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Journal of
Experimental Psychology

VOL. X., No. 4 AUGUST, 1927

AN EXPERIMENTAL STUDY OF APPARENT TACTUAL MOVEMENT

BY WILBUR S. HULIN

Princeton University

I. INTRODUCTION

Statement of the Problem. The purpose of the present investigation was to determine the possibility of compulsory conditions for the arousal of apparent tactual movement by a succession of temporally and spatially discrete stimuli. The limiting range of values was sought which would arouse tactual movement. A large number of repetitions were made to show the distribution of frequency of movement within this range; and at the same time introspective analyses were given by the observers.

The present need in the study of apparent tactual movement is a satisfactory determination of the relative importance of the stimulus-setting as against subjective attitude. The solution of this problem seems to depend first of all upon the question whether compulsory stimuli can be found for the arousal of apparent tactual movement.

Historical Setting. The experience of apparent movement has become an important problem in the fields of vision, audition and touch. The impetus for the present wide-spread interest in the problem, especially in the field of vision, came from the assertion by Wertheimer[1] in 1912 that the apparent movement in vision is an unique experience consisting of an unanalyzable 'pure movement' wherein no object is perceived and even the attribute of quality is absent. Wertheimer labels this pure movement the 'phi-phenomenon' and suggests a physiological explanation in terms of

[1] M. Wertheimer, Experimentelle Studien über das Sehen von Bewegung, *Zsch. f. Psychol.*, 1912, 61, 161–265.

short-circuits occurring within the visual cortex. Wertheimer's work is an important point of departure because the alleged simplicity of the phi experience and its physiological basis exclude the various perceptual mechanisms suggested in the previous explanations of illusory movement.

In confirmation of Wertheimer's description and explanation Korte [2] presents laws governing the stimuli which arouse the phi. The three principal laws are: (1) Spatial separation (optimal for phi) varies directly with intensity. (2) Intensity (optimal) varies inversely with temporal interval. (3) Temporal interval (optimal) varies directly with spatial separation.

From the date of these studies much confirmatory and controversial literature has developed concerning the alleged experience. The school of the *Gestalt-Theorie*, which credits its origin to Wertheimer's experiment, has accepted the phi as an outstanding example of the non-additive configurations with which the doctrine is concerned, and has offered many experimental supplementations to this phenomenon.[3]

A controversial attitude toward Wertheimer's phi is found in the description given by Dimmick [4] of a 'gray flash' which constitutes the existential correlate of the visual movement, and in the description by Higginson [5] of bodily kinæsthesis and eye-movements which are sometimes concomitant with visual qualities. Benussi [6] implies, and Hillebrand [7] and Higginson definitely present, contradictions to Korte's laws in the field of vision.

In audition the phenomenon of apparent movement has been experimentally demonstrated by Burtt [8] and Scholz,[9] both of whom describe experiences comparable to the visual phi and demonstrate the validity of some of Korte's laws in this sense department. Scholz is unable, however, to confirm Korte's law of direct variation of space and time in audition (or in vision or touch), and Burtt did not deal with this law in audition.

In touch the perception of movement from successive stimuli has been studied with varying results. This tactual problem is the object of the present investigation, and a brief review of each of the previous experiments is necessary in order to understand the questions which now require solution.

In 1913 Benussi [10] introduced the first direct study of apparent tactual movement.

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[2] A. Korte, Kinematoskopische Untersuchungen, *Zsch. f. Psychol.*, 1915, 72, 193–296.

[3] For a review of the visual experiments see G. D. Higginson, The visual apprehension of movement under successive retinal excitations, *Amer. J. Psychol.*, 1926, 37, 63–115.

[4] F. L. Dimmick, An experimental study of visual movement and the phi-phenomenon, *Amer. J. Psychol.*, 1920, 31, 317–332.

[5] Higginson, *op. cit.*

[6] V. Benussi, Versuche zur Analyse taktil erweckter Scheinbewegungen, *Arch. f. d. ges. Psychol.*, 1917, 36, 84, 104.

[7] F. Hillebrand, Zur Theorie der stroboskopischen Bewegungen, *Zsch. f. Psychol.*, 1922, 89, 262–272.

[8] H. E. Burtt, Auditory illusions of movement, This JOURNAL, 1917, 2, 63–75.

[9] W. Scholz, Experimentelle Untersuchungen über die phänomenale Grösse von Raumstrecken, *Psychol. Forsch.*, 1925, 5, 219–272.

[10] V. Benussi, Kinematohaptische Erscheinungen, *Arch. f. d. ges. Psychol.*, 1913, 29, 385–388.

Before this date there is only casual reference given to the experience. Judd [11] found, in using successive two-point stimulations, that when the second point was presented before the cessation of the first "with the application of the second stimulus there was sometimes simply an increase of pressure accompanied by a blunting or diffusion of the sensation." Von Frey and Metzner [12] report that in successive two-point stimulation (*e.g.*, with an interval of 4/3 sec) a description was given of a 'shifting' or 'stroking' of the stimulus along the skin.

Benussi set out to check by means of experiments on apparent tactual movement the work of Wertheimer which was quite at variance with Benussi's own previous kinematoscopic researches. In 1917 he presents the following results.[13] With temporal intervals of 90–120 sigma and spatial separations of 3–20 cm, fluttery 'shiftings' within each of the successive areas were aroused; with temporal intervals of 240–260 sigma and spatial separations of 3–12 cm, 'stroking' movements from the first to the second pressure spot were aroused; and with temporal intervals of 360–620 sigma and spatial separations of 3–20 cm, 'bow' movements, a sort of leaping through the air, were aroused. Immediately after movement had been aroused at a 4 cm separation, Benussi also obtained with the same temporal intervals similar reports at spatial separations of 70 cm and 140 cm (the latter being the distance between the fingers on the two outstretched arms). In these greater spatial separations Benussi suspects that a constant attitude has been carried over from the observations with the 4 cm separation, and he suggests that the mutual variations of space and time which arouse movement cast doubt upon Wertheimer's hypothesis that there need be greater distance between cortical points for the greater temporal intervals of the excitations. Benussi considers space more important than time, although he finds an optimal constant ratio between temporal interval and the durations of each stimulus which equals 1 : 4. (Yet a temporal overlap of stimulations, *i.e.* a minus temporal interval, arouses movement.) Benussi states that he never finds 'pure movement,' although he admits that the most definite movement is only of the most impalpable sort, of a mere 'something.' The experience of movement depends upon a temporal judgment of a supra-sensory order determined by memorial processes. Benussi claims that his observers can, by subjective grouping or isolating of impressions or by attentive emphasis upon one of the points of impression, determine the arousal of one or another type of movement experience without any change in the objective temporal interval.

Burtt [14] directly applies Korte's laws to tactual movement and reports that his results agree with the direct variation of space and time. He obtained movements with spatial separations of 8–16 cm and temporal intervals of 15–72 sigma. The duration of each stimulus was always 60 sigma. Various characterizations of movement were reported, such as 'roll,' 'snake-effect,' 'loop,' *etc.* Burtt rejects the short-circuit theory and suggests, instead, that there may be a continuity of motor adjustment (*e.g.*, with the head and eyes) from the first to the second stimulation which gives the illusion of movement. Support for this suggestion is found in Benussi's failure to arouse movement on the forehead where motor adjustment is difficult.

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[11] C. H. Judd, Ueber Raumwahrnehmungen im Gebiete des Tastsinnes, *Phil. Stud.*, 1896, 12, 425–428.

[12] M. v. Frey & S. R. Metzner, Die Raumschwelle der Haut bei Successivreizung, *Zsch. f. Psychol.*, 1902, 29, 179–180.

[13] Benussi, *Arch. f. d. ges. Psychol.*, 1917, 36, 59–135.

[14] H. E. Burtt, Tactual illusions of movement, this JOURNAL, 1917, 2, 371–385.

Whitchurch [15] and Andrews [16] sought to determine the existential correlates of apparent tactual movement. Whitchurch restricts herself to small spatial separations of 2.1–5.5 mm so as to avoid visual association. With a duration of 150 sigma she obtained optimal temporal intervals at 100 sigma for cutaneous movement and 75 sigma for subcutaneous movement. Subcutaneous stimulation aroused a greater percentage of movement. The various forms of full and part movement described are said to depend upon several primary integrations of different existential data. But the only valid description of 'process' given by Whitchurch is of 'spreading pressure.' The characterization of pure phi is given to those moving pressures which have no distinct points of beginning or ending. Sometimes there is an initial static pressure from the edge of which a spread of pressure develops after a pause. Whitchurch considers that apparent tactual movement depends upon a higher perceptual order than does the visual, and so there is less probability of determining a compulsory setting for the tactual.

Andrews made the 'bow' movement his particular object of investigation. In his preliminary series he intended to isolate the conditions arousing the 'bow,' but he found that his two uninstructed observers reported no sort of apparent movement, although his trained observer reported some sort in about 45 per cent. of the experiments. Thus it seemed that a proper subjective attitude is necessary. This subjective attitude was indirectly suggested to the observers by repeating the two successive contacts a number of times in rapid succession with a pause between the pairs of twice the temporal interval used between each member of the pair. Temporal intervals of 100–1600 sigma, spatial separations of 2–10 cm and a duration of 150 sigma were used. With the series of repetitions all observers reported a gradual building up of the perception of movement, generally from 'discrete points' through 'unimembral movement' and 'bimembral movement' to 'full movement.' Except for the fact that a longer series of repetitions more frequently aroused movement, no agreement concerning the quantitative relations could be established. Andrews concludes that the perception of movement in or on the skin is inferred from a spatial and temporal integration of pressure, and that this perception is of a different sort from the subjective processes which carry the meaning of 'bow' movement through the medium of associated visual and kinæsthetic images or incipient sensations.

Scholz [17] found that optimal apparent movement (in vision, audition and touch) traverses a phenomenal extent which is much shorter than the extent aroused by the excitations which are experienced other than as optimal movement.[18] In touch, however, the phenomenal shortening is not so well correlated with movement as in vision. There are two reasons: (1) Approximate simultaneity in temporal interval induces a great shortening in the tactual extent (which corresponds to the usual fact that the simultaneous two-point limen is higher than the successive). (2) In touch a very small spatial separation (2 cm) with a small temporal interval (a temporal overlap) arouses a fusion of the excitation into a single contact which is equivalent to a hundred per cent. shortening; yet with a large temporal interval (200–800 sigma) when

[15] A. K. Whitchurch, The illusory perception of movement on the skin, *Amer. J. Psychol.*, 1921, 32, 472–489.

[16] W. A. Andrews, Haptical illusions of movement, *Amer. J. Psychol.*, 1922, 33, 277–284.

[17] Scholz, W., *op. cit.*

[18] Benussi (*Arch. f. d. ges. Psychol.*, 1913, 29, 387) noted this same phenomenal shortening with tactual movement.

the excitations are experienced as a succession a phenomenal overextension occurs within the same spatial separation. So in touch, fusion reduces the range of possible stimulus values favoring movement, and moreover the phenomenal overextension does not occur with optimal movement as it does in vision. Furthermore, Scholz found no strict regularity in the relations governing optimal movement, and his results contradict Korte's space-time law (in opposition to Burtt's verification of it). Qualitatively the movement experience is palpable, 'of something touching.' The 'bow' movement is frequent, and while the end contacts seem like the experience of a stick brushing across the skin the 'bow' part of the movement is an intangible, indescribable experience. Scholz (like Benussi) found that a synthetic attitude is more favorable than the analytic for the movement experience. Scholz explained these phenomena according to the Hartmann-Köhler [19] modification of Wertheimer's theory.

Summary of Historical Setting. In view of the above experiments it seems evident that the apparent tactual movement is a perceptual complex which may be introspectively analyzed into several factors. Benussi and Scholz indicate that there is reference to an object, that 'something' moves; Whitchurch and Andrews indicate that there is an immediate sensory datum, some sort of pressure-spread. These indications present a contrast to the alleged *objektlose* and *unanschauliche* nature of Wertheimer's phi. Furthermore, there seems to be a separability between the peripheral excitations and the more subjective factor of attitude. The distinction by Whitchurch of cutaneous and subcutaneous movement indicates the significance of the particular sense organ involved. The attitudinal factor of 'attention,' noted by Benussi, Andrews and Scholz, and the introspective reports of bodily kinæsthesis and eye movements, obtained by Andrews, represent the more subjective aspect of the perception. And according to Benussi and Andrews the observer's attitude plays a preponderant rôle in the arousal of apparent movement. On the quantitative side, movement has been aroused between the spatial separations of 2 cm and 140 cm, and between the temporal intervals of − 100 sigma (simultaneity) and 2200 sigma. No one has established compulsory conditions. Korte's laws have received only a doubtful verification in touch. And the optimal ratios of space and time determined by the several experiments invite further verification.

[19] L. Hartmann, Neue Verschmelzungsprobleme, *Psychol. Forsch.*, 1923, 3, 319–396; Köhler, W., Zur Theorie der stroboskopischen Bewegung, *ibid.*, 397–406.

II. The Experiments

A. Apparatus. In the present experiment[20] the volar surface of the left forearm was stimulated by two successive pressure points. A modified form of Benussi's 'Kinohapt'[21] was used in applying the stimuli. The pressure points consisted of two bluntly pointed hard-rubber tips mounted on stiff wire. The diameter of the tips was about 0.75 mm at the limiting depth of their depression into the skin. In order to avoid any disturbing impact when applying the stimuli the points were held in suspension 0.5 mm above the skin and were allowed to drop by their own weight. The weight of the points, regulated by interchangeable slotted brass washers fitted on the points, determined the intensity of the pressure. The intensity was thus measured in actual grams. Each stimulus point was actuated by a solenoid, as follows:

Through the center of each solenoid a loosely fitting brass rod was held in by a light spring. The stimulus point was mounted on the end of the brass rod by a freely sliding collar which normally rested on a soft rubber bushing. When the circuit was completed through the coil the rod was expelled downward and the stimulus point and collar fell with it until the hard-rubber tip rested with its full weight upon the skin. When the circuit was broken the spring within the coil pulled up the rod and with it the point from off the skin.

The stimulus points were set out beyond the edges of the solenoids so that they could be brought together at a zero spatial separation. The solenoids were fastened to a bar along which they could be moved to various separations. The temporal intervals of stimulation were determined by contacts upon a revolving drum driven at a constant speed by a motor.

B. Procedure. The conditions of successive stimulation were kept as simple and uniform as possible so that a large body of data could be acquired for a few definite stimulus

[20] The experiment was conducted under the direction of Professor H. S. Langfeld and Professor E. G. Boring for whose generous aid the writer is very grateful. The experiments were performed at Harvard University during 1923-24 and at Princeton University during 1924–25. At Harvard the observers were Ce, Fr, Go and Hu; at Princeton they were Ca, Do and Li. All the *O*s possessed some previous experience in laboratory observation, all had discussed the purported phi-phenomenon, but none was aware of ever having experienced apparent tactual movement.

[21] V. Benussi, *Arch. f. d. ges. Psychol.*, 1913, 29, 386.

values. The same contact points were always employed, and a weight of 4 gr was always used as the intensity value for each contact. The stimuli were always presented along the longitudinal axis of the arm, and in the proximal-distal order of succession. (With each of three *O*s about 25 haphazard *Vexirversuchen* of the distal-proximal order were tried, but always were recognized, so were abandoned.) With Ce, Fr and Hu a proximal cutaneous spot was tatooed and always used for the initial stimulation; with the other *O*s the stimulations were confined to the same general area of the forearm, which was devoid of hairs. The arm was held comfortably in a fixed position in an upholstered arm-rest. A large cardboard screen was generally interposed between *O* and the apparatus. Each experimental sitting lasted an hour. *O* was allowed frequent rest.

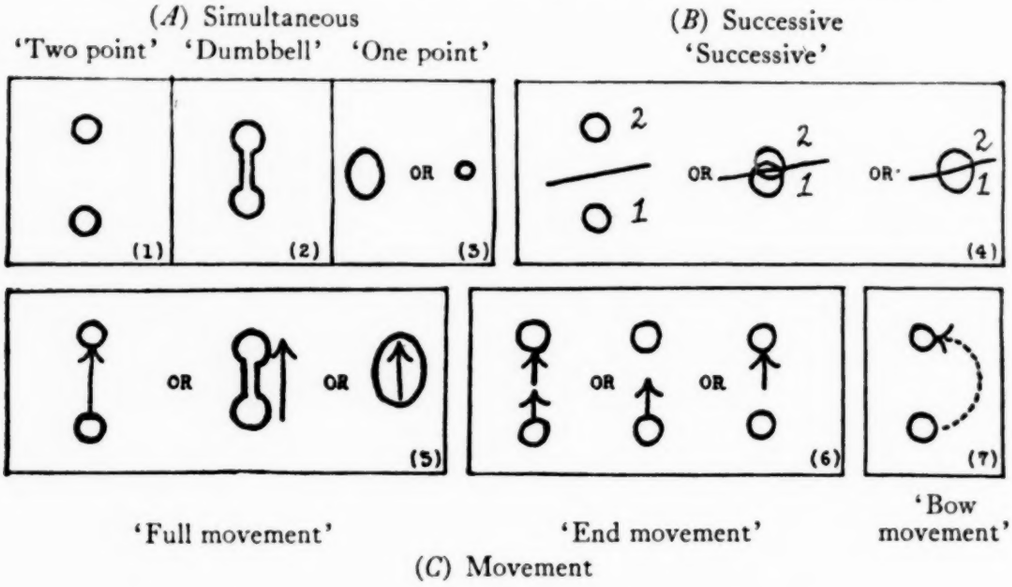
The Intervals of Space and Time. The duration of each stimulus was always 150σ. The temporal intervals counted from the cessation of the first stimulus until the commencement of the second. (Thus, immediate succession would be counted as 0σ interval, simultaneity as $-$ 150σ, and + 60σ would represent an interval of 60σ in which no stimulation occurred after the cessation of the first stimulus and before the onset of the second.) With the four *O*s, Ce, Fr, Go and Hu, the following temporal intervals were used: $-$ 150, $-$ 75, 0, + 60, + 150 and + 300 (σ); with the three *O*s, Ca, Do and Li, the temporal intervals used were: $-$ 150, $-$ 75, 0, + 75, + 150, + 225 and + 300 (σ). The spatial separations for *O*s, Ce, Fr, Go and Hu, were 50, 70 and 100 mm; for Ca, Do and Li, they were 5, 25, 50, 75, 100, 125 and 150 mm. The temporal intervals were varied in haphazard order with each trial; the spatial separations were varied with every 15 trials.

C. The Method of Report. *O* was asked to draw with a pencil upon paper a graphic characterization of each cutaneous perception aroused. This sort of report made it necessary that *O* be given a certain preparation concerning the nature of the experiment. So before the experimental series were commenced *O* was instructed thus:

"In the following experiments you are to close your eyes and after a ready signal you will be stimulated upon the skin of your arm. Immediately after each stimulation you are to open your eyes and report your experience by drawing upon the paper before you a diagram such as you might make if you were actually tracing upon your left forearm the exact size, form and extent of your tactual experience. The diagrams should be drawn as nearly as possible according to the accompanying symbols." (See Chart A.)

Chart A

Graphic Symbols upon which the Observer is to Base His Reports



(C) Movement

These symbols were explained to *O* as follows:

(*A*) *Simultaneous.* Where no temporal interval is noted in the tactual perception dots, circles or figures, drawn according to the phenomenal extent and pattern as perceived on the arm, represent the perception. (1) 'Two points' represent two distinctly separate areas or spots of pressure. (2) 'Dumbbell' represents patterns of double pressure which are not spatially separated. There may be a considerable variety in the form and extensity of these patterns. (3) 'One point' represents a single undifferentiated spot of pressure.

(*B*) *Successive.* (4) These diagrams represent the temporally discrete succession of two pressures which may occur in separate spatial areas or upon a single area. This category is based upon drawings of two dots or circles (separate or overlapping), or of a single drawing or dumbbell, with a transverse line dividing each drawing into two halves which are numbered '1' and '2' so as to indicate the order of succession.

(*C*) *Movement.* (5) 'Full' movement represents the experiences of a continuous shift or irradiation of one contact across a certain extent of skin; the moving pressure is temporally and spatially continuous. In this category movement is represented by an arrow drawn parallel with, or definitely connecting, the end points of the pressure extent; two circles connected with an arrow indicates merely an impalpable or only the vaguest pressury connection between two emphasized end points; single large or long circles, or dumbbells, with an arrow drawn alongside or inside, represent a more definite

pressure continuity throughout the course of the movement. (6) 'End' movement represents a spatial discreteness between two pressures one or both of which seem to move across part of the intervening space, the first moving part way toward the second and the second continuing the movement outwards from a point somewhat beyond the spot where the first pressure stopped. All single or dual part-movements are grouped under this category, and are represented by two points or circles from one or both of which arrows extend a brief distance. (7) 'Bow' movement represents a very objective sort of perception of something touching the skin and then jumping through the air to another point of contact; there is temporal continuity but not spatial. The movement through the air is represented by dotted lines and arrow heads.

(*D*) *Other experiences* may occur which cannot be characterized according to the above symbols. In this case you may draw any other symbols which seem suitable. But be sure to draw them the same size as the cutaneous pattern seems to be.

A constant reference to the symbols was allowed. This method of report was agreeable to all *O*s, and the method seemed to offer a practical way in which to measure the extensity and spread of the pressure experiences. The use of the symbols permitted the possibility of two influences upon *O*'s attitude; (1) The symbols might give a free exercise to visual and kinæsthetic concomitants in consequence of the visualized and graphic character of the reports. (Whitchurch had reported the elimination of visual associations in tactual movement.) Yet in consideration of the history of tactual problems, such as the two-point limen [22] and tactual localization,[23] it seemed that visual, kinæsthetic and other associations might be expected as an inevitable part of the perceptual complexes aroused in the present experiment. (2) In presenting the symbols and the types of movement (shown in Chart A) to *O* as a sample upon which to base his reports there may have been present a strong factor of suggestion. But *O* was warned against the stimulus-error and was rehearsed in the various existential correlates which might occur in the tactual perceptions. *O* was urged not to make any effort to get the experience of movement, but to wait passively for any type of experience, because all experiences were equally important. This 'procedure with knowledge' seemed justified since *O* was already acquainted with the literature concerning

[22] *Cf.* V. Henri, *Raumwahrnehmungen des Tastsinnes*, 1898, 5–89; also E. G. Boring, The stimulus-error, *Amer. J. Psychol.*, 1921, 32, 449–471.

[23] *Cf.* Henri, *op. cit.*, 90–141.

the phi and was aware of the various types of movement usually reported. *O*'s preparation contributed toward a standardization of his background of knowledge and helped to make his subjective attitude a constant factor. A standardization of the drawings was necessary if they were to be quantitatively comparable. The haphazard variation of the stimuli and the screening of the apparatus served as an immediate restriction upon too much suggestion.

In addition to the graphic reports *O* was asked to supplement his drawings with brief introspective protocols. The protocols were reported whenever *O* desired during the experimental hour.

III. The Results

A. The Types of Perception. The seven *O*s reported a total of 13,500 judgments. Most of these judgments can be classified according to the types suggested in the preliminary instructions. The final classification is as follows: 1. *Successive* (SUC), 2. *Full movement* (FM), 3. *End movement* (EM), 4. *Single point* (SP), 5. *Two point* (TP), 6. *Dumbbell* (DB), 7. *Bow movement* (BM) and one new type, 8. *Inner movement* (IM). IM characterizes many of Ca's experiences of one or two unstable contacts which flutter within their separate areas of stimulation, and are represented by circles within which arrows point in both directions. Observer Do also reports IM. Another variation of experience is reported by the drawing of three, four or more circles in a row and numbered serially which indicates that the cessation of each contact is displaced from the spot where it began; these 'series' or 'walks' are called FM when the circles are evenly distributed between the end-points, and are called EM when grouped closely to the end-points. There are 13 reports of apparent distal-proximal (reverse) movement which are classified according to their similarity with the above types. When *O* was doubtful as to his report a judgment of the original impression was insisted upon because a repetition of the stimulus frequently arouses a surprisingly different experience.

TABLE I

SHOWING THE FREQUENCY AND DISTRIBUTION OF THE TYPES OF PERCEPTION REPORTED BY THE SEVEN OBSERVERS

1 O	2 Int	3 JS mm	4 SUC %	5 FM %	6 EM %	7 SP %	8 DB %	9 TP %	10 IM %
	5 MM								
Ca	−150	0.0				100			
	− 75	0.0		16					84
	0	1.1		22		2			76
	+ 75	2.3	26	54		2			18
	+150	2.8	24	68					8
	+225	4.8	22	64	12				2
	+300	4.7	72	28					
Do	−150	0.0				100			
	− 75	0.2		58		40			2
	0	0.0	28			72			
	+ 75	0.4		66		30			4
	+150	1.2	36	64					
	+225	2.9	88	10	2				
Li	−150	0.0				100			
	− 75	0.0		94		6			
	0	1.6	88	12					
	+ 75	9.3	100						
	+150	11.5	100						
	+225	14.0	100						
	25 MM								
Ca	−150	0.0				100			
	− 75	1.6		68					32
	0	2.5		94		6			
	+ 75	1.9		96		4			
	+150	1.9	40	56		2			2
	+225	6.3	82	18					
	+300	10.2	100						
Do	−150	0.4				98		2	
	− 75	3.6	74	26					
	0	5.5	68	16	14	2			
	+ 75	9.5	84	16					
	+150	8.2	92	8					
	+225	8.6	96	4					
Li	−150	0.0				90		10	
	− 75	1.7	8	92					
	0	7.5	62	38					
	+ 75	11.3	94	6					
	+150	8.2	100						
	+225	12.0	100						
	50 MM								
Ca	−150	0.0		8		92			
	− 75	16.5		100					
	0	24.0		38	62				
	+ 75	32.2	10	12	78				
	+150	25.6			100				
	+225	31.5	64		36				
	+300	36.1	90		10				

1 O	2 Int	3 JS mm	4 SUC %	5 FM %	6 EM %	7 SP %	8 DB %	9 TP %	10 IM %
	50 MM								
Ce	−150	0.0		1		99			
	− 75	0.0		61		37	2		
	0	2.3	23	60		17			
	+ 60	7.0	38	58		4			
	+150	25.5	82	16		2			
	+300	32.8	93	6		1			
Do	−150	3.2	4			74		22	
	− 75	14.4	60	40					
	0	14.4	78	22					
	+ 75	18.7	82	18					
	+150	24.6	100						
	+225	31.9	100						
Fr	−150	0.0		2		54	44		
	− 75	2.9		55	29	14	1		1
	0	5.4	13	34	53				
	+ 60	13.2	82	3	15				
	+150	17.5	96		4				
	+300	19.7	99		1				
Go	−150	0.0				89	11		
	− 75	10.8	34	63		3			
	0	13.7	49	47		2	2		
	+ 60	25.3	98		2				
	+150	29.1	100						
	+300	33.1	100						
Hu	−150	0.0		7		52	41		
	− 75	1.8	4	83	13				
	0	5.8	13	71	16				
	+ 60	11.3	22	43	35				
	+150	17.9	82	7	11				
	+300	24.7	95		5				
Li	−150	0.0				68	32		
	− 75	4.1	68	32					
	0	7.3	84	16					
	+ 75	8.3	82	18					
	+150	14.2	88	12					
	+225	16.4	100						
	70 MM								
Ce	−150	0.3		6		92	1	1	
	− 75	0.1	3	33		64			
	0	0.8	8	74		17	1		
	+ 60	5.3	33	62		5			
	+150	17.5	80	19		1			
	+300	22.9	99	1					
Fr	−150	1.3		29	1	41	23	6	
	− 75	1.2	4	81	1	12			2

TABLE I (*Continued*)

1 O	2 Int	3 JS mm	4 SUC %	5 FM %	6 EM %	7 SP %	8 DB %	9 TP %	10 BM %
	70 MM								
Fr	0	8.3	34	28	34				4
	+ 60	12.0	41	10	40				9
	+150	17.7	78	4	18				
	+300	28.6	100						
Go	−150	1.2		5	1	53	29	12	
	− 75	5.7	4	84	6	5		1	
	0	10.2	32	67	1				
	+ 60	32.0	63	14	23				
	+150	28.1	95	1	4				
	+300	23.9	90	3	7				
Hu	−150	0.0		2		16	43	39	
	− 75	0.7	6	93	1				
	0	1.7	2	91	7				
	+ 60	11.9	15	45	39				1
	+150	26.7	59	10	31				
	+300	14.7	26	9	65				
	75MM								
Ca	−150	0.5		20		76	4		
	− 75	11.1	4	74	18	4			
	0	21.4	20	56	20				
	+ 75	24.2	32	34	30				4
	+150	33.7	48	14	38				
	+225	37.8	76	2	18				4
	+300	39.5	100						
Do	−150	18.2	20	26		10		34	10
	− 75	38.8	78	12					10
	0	51.0	86	4	8				2
	+ 75	58.7	70		30				
	+150	61.3	68		32				
	+225	67.9	90		6				4
Li	−150	1.4	10	18		58	14		
	− 75	10.3	76	24					
	0	13.1	96	4					
	+ 75	13.0	100						
	+150	14.5	100						
	+225	15.2	100						

1 O	2 Int	3 JS mm	4 SUC %	5 FM %	6 EM %	7 SP %	8 DB %	9 TP %	10 BM %
	100MM								
Ca	−150	0.0		2		98			
	− 75	10.8		100					
	0	14.7		94	6				
	+ 75	23.2		88	12				
	+150	43.8	4	10	86				
	+225	41.1	24		76				
	+300	49.5	86		14				
Ce	−150	0.0		9		82	9		
	− 75	1.9	5	46		43	3	3	
	0	14.0	76	18			6		
	+ 60	17.0	82	18					
Do	−150	41.5	16				18	50	16
	− 75	52.8	28		72				
	0	61.8	40		60				
	+ 75	55.3	100						
	+150	57.1	100						
Fr	−150	62.6						100	
	− 75	46.8	10		90				
	0	52.9	50		50				
	+ 60	65.4	90		10				
Go	−150	24.2	13	3		13	7	64	
	− 75	26.2	66	17	17				
	0	34.6	97		3				
	+ 60	36.4	100						
Hu	−150	18.3					12	88	
	− 75	42.7	65		35				
	0	56.6	100						
	+ 60	54.0	100						
Li	−150	3.8				4	64	32	
	− 75	7.0	38	62					
	0	16.5	100						
	+ 75	18.4	100						
	+150	21.3	100						
	+225	19.4	100						

TABLE I (*Concluded*)

1 O	2 Int	3 JS mm	4 SUC %	5 FM %	6 EM %	7 SP %	8 DB %	9 TP %	10 BM %	1 O	2 Int	3 JS mm	4 SUC %	5 FM %	6 EM %	7 SP %	8 DB %	9 TP %	10 BM %
	125MM										125MM								
Ca	−150	0.0				40	10	50		Li	−150	31.5						100	
	− 75	22.1		94	6						− 75	14.9	32	68					
	0	39.0		96	4						0	12.8	90	10					
	+ 75	40.2	12	88							+ 75	12.9	100						
	+150	35.8	18	78	4						+150	14.3	100						
	+225	59.7	76	24							+225	15.2	100						
	+300	58.0	100								150MM								
										Ca	−150	20.9							
Do	−150	105.2						100			− 75	24.3	54	16	30		18	82	
	− 75	99.8	100								0	37.6	100						
	0	90.4	100								+ 75	49.8	100						
	+ 75	95.8	100																
	+150	102.3	100							Li	−150	89.5						100	
	+225	99.6	100								− 75	92.4	32					68	
											0	90.6	100						
											+ 75	89.6	100						

B. Frequency and Distribution of the Types of Perception. Table I shows the frequency and distribution of the eight types of perception reported by the seven *O*s. With Ce, Fr, Go and Hu there are recorded 100 judgments for each practical combination of temporal and spatial interval; with Ca, Do and Li, 50 judgments were taken on each practical combination. ('Practical' combinations are those within the limiting temporal and spatial values at which no more reports of any sort of movement experience were given by *O*.) Movement was reported by some at values which were beyond the limits of movement for others. All the limits for Ce, Fr, Go and Hu were not reached, owing to lack of time; but the greater range of values presented to Ca, Do and Li seems to include the probable boundaries of the stimuli arousing movement for these three *O*s.

Table I is divided into eight sections. Each section represents one of the eight spatial separations used. In each section, column 1 shows the names of the *O*s (O), column 2 shows the temporal intervals (Int), column 3 shows an average of the judgments of the spatial separations (JS) for each temporal interval, and columns 4–10 show the percentages of frequency of each type of perception. The sum of the percentages (of the types of perception) across one horizontal

line equals 100 per cent. and represents all the judgments given by one *O* for one temporal interval at one spatial separation.

(1) *Temporal Interval vs. Spatial Separation.* In order to determine the importance of the objective stimulus values in the arousal of the types of perception, it is necessary to make a separate analysis of the influence of temporal interval and of spatial separation. For the sake of simplicity the eight types of perception may be reduced to three headings, which are as follows:

Simultaneity (SIM), which includes SP, DB and TP;
Optimal (OPT), which includes FM, EM, BM and IM;
Successive (SUC), which includes SUC.

For a general survey all the percentages found in Table I may be grouped under the three headings, SIM, OPT, SUC. Under each heading, first the percentages of all *O*s at all spatial separations are totalled together and averaged for each temporal interval, then the percentages of all *O*s at all temporal intervals are totalled together and averaged for each spatial separation. Thus a group measure is obtained for each of the two variables of space and time.

Table II

Distribution of the Average Percentages of SIM, OPT, SUC and FM as Plotted against Temporal Interval

(Each percentage is the average of all the spatial separations of all seven *O*s at a given temporal interval)

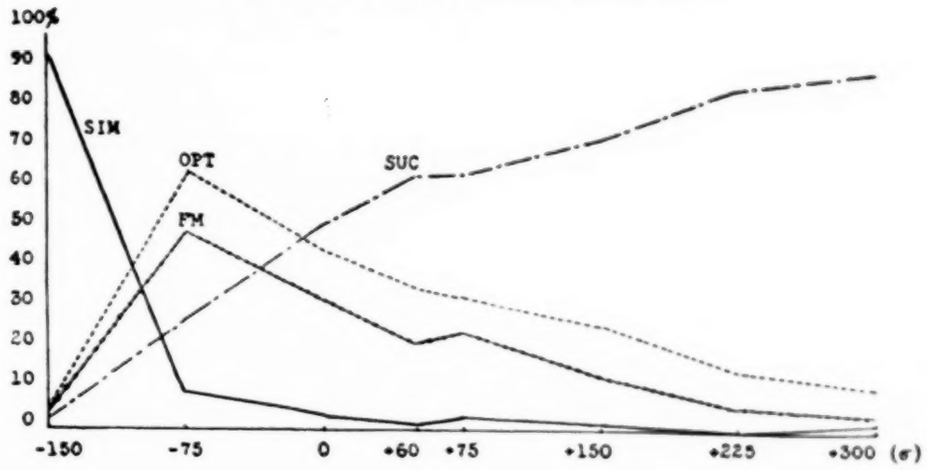
Int (σ)	SIM %	OPT %	SUC %	FM %
−150	92.8	5.1	1.9	4.3
− 75	9.4	63.7	26.6	49.6
0	3.9	44.8	51.1	31.6
+ 60	.7	35.5	63.6	21.0
+ 75	1.8	33.6	64.6	24.8
+150	.1	27.4	71.9	14.1
+225	.00	15.6	84.3	6.7
+300	.07	10.6	89.2	3.3

In the manner just described Table II shows the distribution of SIM, OPT and SUC according to each temporal

interval. Also a similar average of FM for all *O*s at all spatial separations is shown for each temporal interval. Here FM, considered as the most vivid and complete type of movement, can be compared with the movement experience in general as shown by OPT. Chart B is a graphic representation of Table II.

CHART B

A GRAPHIC REPRESENTATION OF TABLE II



From Table II it seems evident that temporal interval effects a certain amount of determination in the type of experience aroused by the successive tactual stimulations. With practically no inversions, SIM quickly drops to nearly zero frequency, SUC steadily rises from -150σ, and OPT reaches a decided peak at the interval of -75σ. At the -75σ interval 63 per cent. of all the reports given are of some sort of movement. FM also reaches a decided peak at the -75σ interval, and FM constitutes 49.6 per cent. of all the judgments reported at this interval of temporal overlap. (Benussi and Scholz report movement at temporal overlaps.)

Table III shows, in like manner, the distribution of SIM, OPT and SUC according to each spatial separation. Chart C is a graphic representation of Table III.

From Table III a negative evidence may be inferred concerning the influence of spatial separation. Here it is seen that SIM, OPT and SUC run nearly parallel in their frequencies between 5 mm and 150 mm. Except for one

inversion at 70 mm the OPT curve declines steadily from 5 mm to 150 mm. And with only a frequency of 5.7 per cent. at 150 mm it seems that the spatial limit for OPT has been reached in the present experimental setting.

Table III

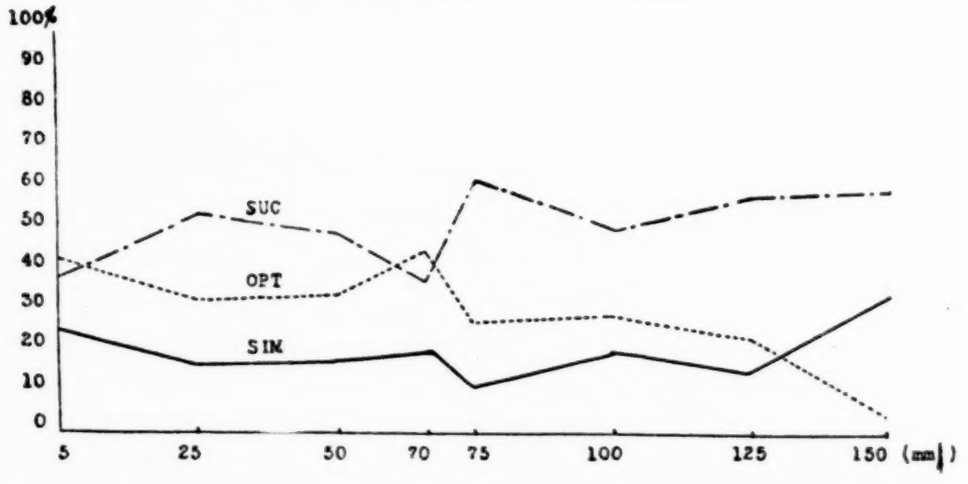
Distribution of the Average Percentages of SIM, OPT and SUC as Plotted against Spatial Separation

(Each percentage is the average of all the temporal intervals of all seven *O*s at a given spatial separation)

Sep'n (mm)	SIM %	OPT %	SUC %
5	23.7	40.2	36.0
25	16.5	30.8	52.6
50	17.7	32.6	49.6
70	19.2	44.4	36.3
75	10.5	27.4	61.7
100	19.8	28.9	50.5
125	15.7	24.8	59.3
150	33.5	5.7	60.7

Chart C

A Graphic Representation of Table III



The conclusion to be drawn from Tables II and III is that only the temporal intervals, and these taken as absolute values, are effective factors in the objective determination of tactual movement.

(2) *Individual Variations.* The significance of the agreement between the general curves of FM and OPT in Table II

depends upon the amount of agreement in the individual curves for each *O*. Since FM constitutes 68.6 per cent. of OPT it largely controls the distribution of OPT.

There are 27 individual curves of FM as plotted against temporal interval for the eight *O*s at the eight spatial separations. Of these 27 curves 21 show a decided peak of frequency at the -75σ interval. The other 6 curves show an indefinite scatter. Do, Fr and Hu report no FM with 100 mm, and Li none with 150 mm.

There are 30 curves of OPT as plotted against temporal interval for the eight *O*s at the eight spatial separations. Of these 30 curves 24 show a peak of frequency at the -75σ interval. The peak of OPT at -75σ is determined by FM in 18 cases, by IM in 2 cases and by EM in 4 cases. Of the 24 cases 4 show a 100 per cent. frequency with more than one temporal interval due to the high frequency of other types of movement. These 4 cases and the 7 cases where movement other than FM determines OPT are shown in Table IV.

TABLE IV

SHOWING ONLY THOSE CASES WHERE THE FREQUENCIES OF OPT VARY FROM THE FREQUENCY OF FM

Sep'n (mm)	Obs	Peak of Other Movement	Peak of OPT	Peak of FM
5.....	Ca	IM − 75	− 75	+ 150
25.....	Ca	IM − 75	− 75	+ 75
25.....	Do	EM 0	0	− 75
50.....	Ca	EM + 150	(− 75, 0, + 150) [24]	− 75
50.....	Fr	EM 0	0	− 75
70.....	Hu	EM + 300	0	− 75
100.....	Ca	EM + 150	(− 75, 0, + 75) [24]	− 75
100.....	Do	EM − 75	− 75	no FM
100.....	Fr	EM − 75	− 75	no FM
100.....	Hu	EM − 75	(− 75, 0, + 60) [24]	(0, + 60) [25]
125.....	Ca	EM − 75	(− 75, 0) [25]	0

Table IV suggests that EM appears with significant frequency in determining the trend of OPT. But the distribution of EM in relation to temporal interval and spatial separation is not very definite. The distribution of the

[24] Three 100 per cent. frequencies.

[25] Two 100 per cent. frequencies.

average percentages of EM for all *O*s as plotted against temporal interval may be compared with that of FM as follows:

	Int (σ)							
	− 150	− 75	0	+ 60	+ 75	+ 150	+ 225	+ 300
EM (%).....	.1	9.9	10.5	12.8	7.5	12.6	8.3	7.2
FM (%).....	4.3	49.6	31.6	21.0	24.8	14.1	6.7	3.3

Here it is seen that the frequencies of EM spread relatively more over the large temporal intervals than do those of FM, but the distribution of EM shows no central tendency. Again, the distribution of the average percentages of EM for all *O*s as plotted against spatial separation may be compared with that of FM as follows:

	Sep'n (mm)							
	5	25	50	70	75	100	125	150
EM (%).....	.7	.7	10.9	11.6	10.5	15.1	.7	3.7
FM (%).....	29.2	28.3	21.6	31.2	14.1	13.3	24.1	2.0

Here it is seen that the frequencies of EM spread relatively more over the large spatial separations than do those of FM, but neither type shows any central tendency of distribution.

The individual *O*s show certain variations in their criteria of judgment. For example: (1) Ce and Li never report EM. Since EM accrues around larger spatial separations it seems possible that EM might be related with judgments of two-point, and that no EM would mean few TP. But Li reports next to the highest frequency of TP and Ce reports the least frequency of TP, and the other *O*s correlate poorly in this relation. (2) Ca's frequent report of IM at 5 mm and at 25 mm indicates that this *O* used criteria of judgment somewhat different from those of the other *O*s. (3) The total amount of movement (OPT) reported by the different *O*s also varies considerably. The percentages of OPT in all the reports are as follows: Ca 57.3 per cent., Hu 47.5 per cent., Fr 38.0 per cent., Ce 30.5 per cent., Go 23.0 per cent., Do 18.3 per cent. and Li 12.6 per cent. Thus Ca reports over four times as much movement as Li.

The possibility was suggested that the movement experience might be similar to dumbbell patterns which spread out spatially and temporally with the successive presentation of the two stimuli. If this were true a greater frequency of OPT

or FM should be correlated with a greater frequency of DB, but an inspection of Table I shows no such relation.

Again, the only definite conclusion which can be drawn from the distribution and variations of the quantitative data is that FM and OPT show a decided peak of frequency at the -75σ temporal interval.

C. Judged Spatial Separation. In Table I, column 3, there are presented for each *O* at each interval and separation the averages of the subjective judgments of the spatial separations between the two excitations. These measurements (made with a millimeter scale laid along *O*'s drawings) are limited to the shortest distance between the points or circles; the areas of each pressure are disregarded. Since only the distance between the circles was measured, the exactly juxtaposed circles and the dumbbells had a zero separation, but circles connected only with an arrow have a positive separation.

Table V_a and Chart D show the average judgments of spatial separation reported by all *O*s for each temporal interval. Table V_b and Chart E show the average judgments reported by all *O*s for each objective spatial separation.

TABLE V_a

AVERAGE JUDGMENTS OF SPATIAL SEPARATION BY ALL *O*S FOR EACH TEMPORAL INTERVAL

(Reports upon all objective spatial separations are united into one average under each temporal interval)

Temporal Interval (σ)	Judged Spat. Sep'n (Mm)
− 150	10.44
− 75	17.75
0	22.49
+ 60	23.96
+ 75	28.75
+ 150	25.48
+ 225	30.66
+ 300	28.46

TABLE V_b

AVERAGE JUDGMENTS OF SPATIAL SEPARATION BY ALL *O*S FOR EACH OBJECTIVE SPATIAL SEPARATION

(Reports upon all temporal intervals are united into one average under each objective spatial separation)

Objective Spat. Sep'n (Mm)	Judged Spat. Sep'n (Mm)
5	2.98
25	5.34
50	14.46
70	11.40
75	27.97
100	33.14
125	49.97
150	61.83

CHART D

GRAPHICALLY REPRESENTING TABLE V_a

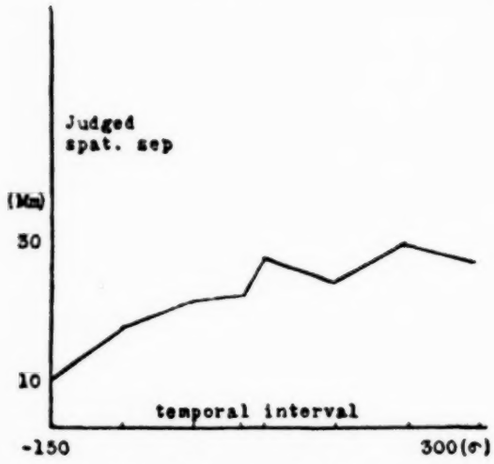
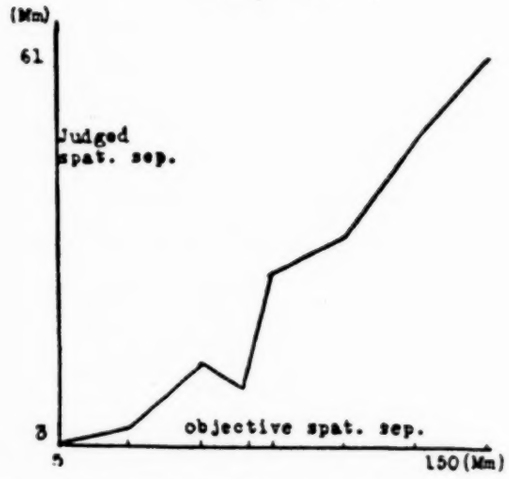


CHART E

GRAPHICALLY REPRESENTING TABLE V_b



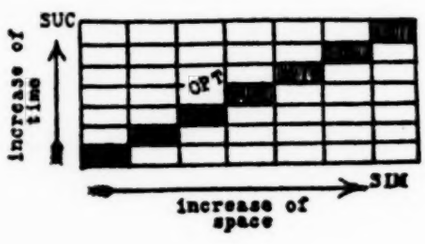
Tables V_a and V_b and Charts D and E show that there is a steady increase in the judged spatial separation either with increased temporal interval or with increased objective spatial separation. And there is no shortening of the phenomenal spatial extent with OPT, as found by Scholz, even though many FM reports consisted of dumbbell drawings which counted as zero separation.

D. Comparison of Korte's Space-Time Law with the Distribution of FM in the Present Experiment. Korte concludes that with increased spatial separation there must be a corresponding increase in the temporal interval if a condition of OPT is maintained. This law is illustrated in Chart F.

CHART F

SHOWING THE THEORETICAL DISTRIBUTION OF OPTIMAL MOVEMENT ACCORDING TO KORTE'S SPACE-TIME LAW

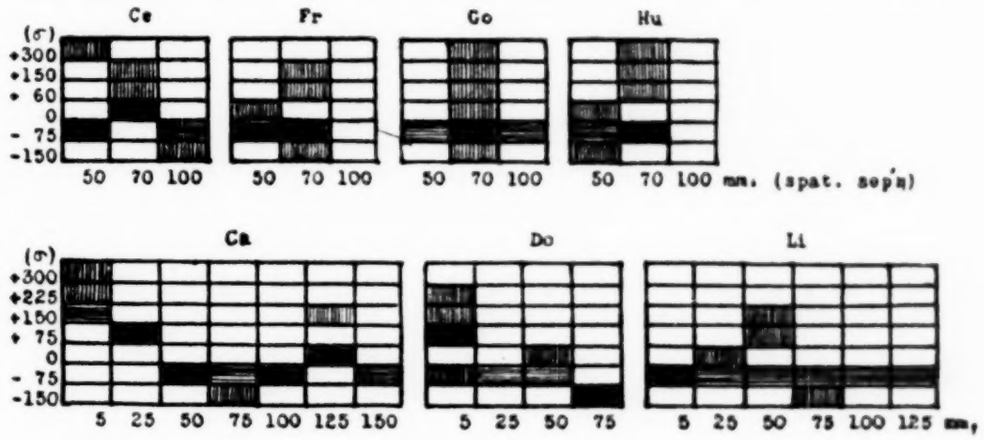
(The shaded squares indicate the theoretical points of highest frequency of *optimal movement* according to the supposition that the increase of temporal interval tends toward *successivity* while the increase of spatial separation tends toward *simultaneity* so that by increasing these two factors together the *optimal* balance is maintained.)



The distribution of FM in the present experiment may be compared graphically with Chart F. In Chart G these comparisons are shown separately for each of the seven *O*s. The distribution of FM is plotted in two ways: (1) each square which shows a *horizontal* shading indicates the individual temporal interval at which the highest frequency of FM occurred for a given spatial separation, and (2) each square which shows a *vertical* shading indicates the individual spatial separations at which the highest frequency of FM occurred for a given temporal interval. (Thus in the chart for Ce by reading down the first column it is seen that the -75σ interval shows the most FM for the 50 mm separation, and by reading across the top line it is seen that the 50 mm separation shows the most FM for the $+300\sigma$ interval, etc.)

Chart G

Showing the Distribution of the Points of Highest Frequency of FM as Plotted against Temporal Interval and against Spatial Separation



In Chart G it is seen that the distribution of FM in the present experiment does not at all correlate with Korte's space-time law. And it is seen that only certain values, such as the -75σ interval, and to some extent the 70 mm separation, are more favorable for FM.

E. Introspective Reports. The verbal protocols represent various degrees of analysis. In some cases it appears that the movement experience is sufficiently definite and simple to be reported at the unqualified level of mere 'movement.' Some examples of these non-analytic reports are as follows:

FM. (Ca) Motion from *a* ending in *b;* but *b* is not a touch, it is only an end; there was no motion at *b*.

(Ca) Movement of a sort; much movement at the ends, yet the intervening area was somewhat movement-like.

(Ce) A long 'rocker' movement.

(Fr) Something rolled lightly over the surface.

(Fr) *a* flowed into *b*.

IM. (Ca) The spots seem to move, yet the direction of the motion is not sensed; the motion seems to quiver within a circle; the experience seems to possess a duality, but the relationship is motion, not direction.

EM. (Go) Proximal rolling, but not quite into the distal which was discrete and appeared very suddenly a short distance from where the proximal was at the time stopping.

On the other hand, Ce reports, I never get what I consider to be phenomenal movement.

From the more analytical descriptions the direct sensorial factors of (i) *pressure spread* and (ii) *pressure perseveration*, and the associative factors of (iii) *visual imagery* and (iv) *kinæsthesis* are illustrated by the following introspections:

(i) *Pressure Spread*

FM. (Fr) There seemed to be an unrolling of a dumbbell pressure pattern; the 'neckness' of the dumbbell represents small intensity as well as the narrowness, and the narrowness seems to come in terms of relationship to the small intensity.

(Go) Rolling pressure; began at proximal and left at distal; no consciousness of a beginning or of an ending; between the two points in time there was a distinct pressure about one eighth of an inch wide.

(Go) Pressure starts at proximal and increases steadily toward the distal while the proximal still remains.

(Hu) The punctiform distal pressure seemed to occur in the outer fringe of the spreading-out bright pressure from the proximal point.

(Li) First sensation drawn out more heavily; seemed like one movement with a pressure after-effect or a tingling irradiation from the first pressure; the pressure spots seemed as one with an intervening irradiation.

EM. (Hu) In the fading of the proximal the distal appeared somewhat separated from the proximal, but the bright pressure fringe around the proximal seemed to draw around the distal as though upon the appearance of the distal point the fringe of the proximal was revived and blended now into the fringe of the distal; this reciprocal spreading-out in sequence to the distal excitation seemed as a bright pressure moving into the distal area.

DB. (Do) Simultaneous, yet a feeling that the two points drew in toward each other.

SUC. (Ce) A discrete spreading out, but no movement.

(Ce) Each pressure seemed to spread out in concentric waves.

SP. (Do) Hard coming down and a softer irradiating release of pressure.

(Do) One spot irradiating pressure outwards.

(ii) *Pressure Perseveration*

FM. (Ce) Two successive pressure areas with a pressure bridge connecting them in time.

(Do) 'Walk'; the series of pressures formed a continuous experience, but involved points of greater pressure intensity which seemed to result from the beginning and ending of each excitation.

SUC. (Do) (1) Pressure coming on; (2) pressure going off; (3) pressure coming on; (4) pressure going off (in the drawing, circle 2 was superimposed on 1, and circle 4 on 3).

(Li) The second was heavier and longer in duration.

(Li) The second was lighter and faded out more quickly than the first.

(iii) *Visual Imagery*

FM. (Fr) Visual image of something moving, yet no experience of tactual movement.

(Fr) Rocking, as of a curved stick of wood along the arm; a vague visual image of such a thing.

(Fr) In spite of the discreteness and successiveness there was a visual image of the proximal stimulus moving along the arm.

BM. (Fr) There was a visual image of something moving in a loop from proximal to distal, and this was sufficiently bound up with tactual sensations to give an experience of tactual bow-movement.

EM. (Hu) Visual image of something gray moving along the arm.

SUC. (Go) In the longer temporal intervals the proximal and distal points are often localized as being closer together than in the shorter temporal intervals because visual imagery, during the longer temporal intervals, projects the expected second stimulation further and further toward the wrist, so that when the distal stimulation really occurs it seems localized at a surprisingly shorter distance away from the first than was anticipated, and the nearness is even exaggerated.

SP. (Ce) Single pressure localized uncertainly by visual imagery.

(iv) *Kinæsthesis*

FM. (Ce) Distinct awareness of eye movements as though from a fixation of the proximal point to a fixation of the distal which accompanied the cutaneous experience.

(Fr) There seems to be an attitude present, an expectation for movement, a sort of leaning forward strain.

(Fr) Bow movement; kinæsthesis throughout the body; a tendency for the whole body to move in a sort of wave accompanying the bow; also visual imagery of a curved motion.

(Hu) In the proximal excitation the vague general kinæsthetic and visual responsiveness is just commencing when the distal excitation follows instantaneously.

(Hu) As the distal occurs there seems to be a tendency to move the body outwards, mostly in the arm stimulated; this kinæsthesis of extending the arm is not distinguishable from the tactual pressure; the arm kinæsthesis and the pressure seem fused, and together with the oculo-motor kinæsthesis and the concrete visual imagery of something gray moving along the arm, the whole complex constitutes a perception of tactual movement.

F. Relation between Tactual Movement and Other Types of Tactual Perception. (i) The factor of pressure spread, reported by the present *O*s, is a factor which was early suggested in the objections raised by Kölliker and Lotze [26] against Weber's '*feste Empfindungskreise.*' Meissner [27] proposed the hypothesis of '*Irradiationskreise*' according to which a punctate stimulus arouses a fairly large surrounding area of sympathetic excitation which expands from out of a core and gradually fades toward the periphery. Several writers [28] have noted the relation between pressure diffusion and the elasticity of the skin. Goldscheider [29] and von Frey [30] claim that Blix's punctiform pressures are bounded with a rim of diffuse pressure. In the studies of tactual movement, Whitchurch claims that at least some of the movements "were conditioned upon directional emphasis within the tactual spread"; and she also says, "the type of FM appearing most often is that of the dumb-bell pattern." Andrews reports "rapid peripheral extension of the pressure quality."

While pressure spread may contribute to the movement perception, yet, in considering that FM is reported at 150 mm, which should be well above the dual limen with successive stimulation, it seems improbable that an unbroken pressure spread could account for the movement at the greater spatial separations. The pressure spread may be one factor among others.

(ii) The factor of pressure perseveration, or 'primary after-sensation,' [31] reported by the present *O*s, seems to have been accepted as a familiar fact by Kottenkampf and Ullrich [32] in 1870. Blix and others [33] suggest that the slow recovery of

[26] *Cf.* R. H. Lotze, *Medicinische Psychologie*, 1852, 404–407.

[27] G. Meissner, *Beiträge zur Anatomie und Physiologie der Haut*, 1853, 44.

[28] *Cf.*, *e.g.*, J. N. Czermak, Weitere Beiträge zur Physiologie des Tastsinnes, *Sitzber. d. Wien. Akad.*, 1855, 18, 379; G. Tawney, The perception of two points not the space-threshold, *Psychol. Rev.*, 1895, 2, 591; M. v. Frey, *Ber. d. Gesell. d. Wiss., Leipzig*, 1897, 49, 463.

[29] A. Goldscheider, *Gesammelte Abhandlungen*, 1898, I, 191 *f.*

[30] M. v. Frey, Ueber Wandelungen der Empfindungen bei formel verschiedener Reizung einer Art von Sinnesnerven, *Psychol. Forsch.*, 1923, 3, 212.

[31] Term established by M. H. S. Hayes, A study of cutaneous after-sensation, PSYCHOL. MONOG., 1912, 14 (no. 60), 30.

[32, 33] *Cf. ibid.*, 1–25.

skin depression involves a perseveration of the pressure quality. Hall and Donaldson [34] explain the incorrect judgments of direction (of moving tactual stimuli) as follows, ". . . the sense of time past since the movement began shrinks in consciousness faster than the sensory after-image arising from the moving point fades. . . ." Von Frey and Kiesow [35] anæsthetized the exact spot of contact stimulation and found that upon the cessation of stimulation a wide circle of pressure was aroused with the elastic springing back of the skin to its normal form. Hayes [36] found that over 45 per cent. of the primary after-sensations (from areal pressure) persisted over 15 seconds.

The duration of pressure after stimulation may also be a contributing factor in tactual movement. Yet it should be remembered that in the present experiment the majority of reports of movement occurred with the temporal overlap, and decreased steadily up to the + 300σ interval. So the pressure perseveration is at most one factor among others.

(iii) The associated visual imagery, reported by some of the present *O*s, is a factor discussed by Wundt [37] in 1862. He asserted that in normal persons the idea of locality on the skin consists mostly of visual associations. Washburn [38] found that associated visual imagery was prominent in judgments made upon those tactual areas which were in the observer's ordinary visual range. In Pillsbury's tactual localization experiment [39] the observers "frequently said that they found it impossible to shut out the visual image." Henri [40] concluded that persons with good visual imagery localize more accurately than persons with poor imagery.

[34] G. S. Hall & H. H. Donaldson, Motor sensations on the skin, *Mind*, 1885, 10, 562.

[35] M. v. Frey & F. Kiesow, Ueber die Function der Tastkörperchen, *Zsch. f. Psychol.*, 1899, 20, 158 f.

[36] Hayes, *op. cit.*, 45.

[37] *Cf.* M. F. Washburn, Ueber den Einfluss der Gesichtsassociationen auf die Wahrnehmungen der Haut, *Phil. Stud.*, 1895, 11, p. 193 (footnote).

[38] *Ibid.*, 204.

[39] W. B. Pillsbury, Some questions of the cutaneous sensibility, *Amer. J. Psychol.*, 1895, 7, 46.

[40] V. Henri, *Raumwahrnehmungen des Tastsinnes*, 1898, 120–126.

Whitchurch's observers eliminated visual associations; but Andrews claims that the visualization is an effective factor.

It seems that concomitant visual imagery may be a contributing factor to all tactual perceptions including tactual movement. But its presence is not yet proved to be compulsory.

(iv) The kinæsthesis reported by the present *O*s suggests the factor of movement which Lotze, Wundt, James and others have claimed to be a contributing element in the development of tactual local sign. The exact rôle of movement varies according to the different theoretical and experimental conclusions. There is the suggestion [41] that tactual points, *e.g.*, on the forearm, are localized according to the distance through which the limb must move in order to shift the contact to the finger tip or elbow, *i.e.*, to points of maximal sensitivity. The posture [42] of the stimulated member has been suggested as a determining factor in errors of localization. Movements and imaged movements of the other arm in pointing,[43] and adjustments, such as the directing of the eyes [44] toward the spot touched, have been studied. There are cases where the inability to move a member has resulted in the inability to localize [45] tactual impressions upon that member, and in other cases there is a lessened ability to recognize two points.[46]

In tactual movement, Burtt suggests that a continuity of motor impulses resulting from the succession of tactual stimuli represents the basis for the continuous movement experience. Andrews gives descriptions (similar to Higginson's for vision) of coördinate head and eye movements which constitute a meaningful background to the immediate sensory experiences.

The factors of visual imagery and kinæsthesis appear with

[41] W. James, *Principles of Psychology*, 1890, II, 160*f*.

[42] C. Spearman, Die Normaltäuschungen in der Lagewahrnehmung, *Psychol. Stud.*, 1906, 1, 426, 456.

[43] W. Lewy, Untersuchungen über das Gedächtniss, *Zsch. f. Psychol.*, 1895, 8, 283.

[44] Henri, *op. cit.*, 108.

[45] A. Gelb & K. Goldstein, *Psychologischer Analyse hirnpathologischer Fälle*, 1920, 157–251.

[46] W. O. Krohn, Sensation areas and movement, PSYCHOL. REV., 1894, 1, 280–281.

a significant persistence. Yet a regular or compulsory participation of these factors in tactual perceptions has not been established. And so the two factors continue to represent only a suggestion that the mechanism of tactual perception in general involves a widespread pattern of response in the organism.

G. The Pattern of Response Involved in Tactual Movement. Apparent tactual movement seems to consist of a complex perception which involves a widespread response of the organism. The movement does not seem to be a simple experience like Wertheimer's alleged phi. An outstanding characteristic of the apparent movement experience, both for vision and for touch, is the state of *bewilderment* which almost every observer reports. A possible explanation for this state of bewilderment is the fact that the total period of exposure of the successive stimuli generally involves a temporal span which is much shorter than that period which is necessary for most types of reaction-time. And so the organism is not yet wholly adjusted at the end of the stimulation.

Higginson [47] discusses this circumstance very aptly. He says:

> "We have clearly demonstrated the remarkable facility of the organism whereby it may attain a functional end under extreme poverty of experiential resources. At times, one is hard pressed to indicate the experiential items involved. The phenomenal basis is often so vaporous and tenuous that one is driven either to central conditions or to observe some somatic factor." "These experiential qualities served to integrate the whole perceptual incorporation; that is to say, to join the otherwise unrelated visual constituents. Verbally stressed exposures, ocular shifts and lingual pursuit movements, as well as slight or incipient rhythmic or non-rhythmic movement of the general musculature furnished an experiential background for the purely visual items to functionate in perception."

In like manner, there is much evidence that in the present experiment there existed an experiential background for the immediate pressure sensations when the perception of movement was aroused. But the variability of the reports and particularly the phenomenological attitude assumed by Ca make it impossible to define any compulsory participation of the contributing factors.

[47] Higginson, *op. cit.*, 111 *f.*

IV. Summary and Conclusions

1. With seven observers 13,500 judgments of two-point pressure stimulation were obtained. The presentation of the two pressure stimuli was varied temporally in eight steps from simultaneity to a positive interval of 300σ between the cessation of the first and the beginning of the second stimulus. Spatially, eight separations from 5 mm to 150 mm were used.

2. Of the 13,500 judgments 29.7 per cent. represented experiences of some sort of apparent movement in the tactual field. The movement experiences were classified into four sorts, 'full,' 'end,' 'inner' and 'bow' movement. The four classes taken together are called 'OPT.'

3. The OPT experiences show a decided peak of frequency (63.7 per cent.) at the -75σ temporal interval. (This interval represents a temporal overlap of the two stimuli.) 'Full' movement, which constitutes 68.6 per cent. of OPT, also shows a decided peak of 49.6 per cent. at the -75σ interval. The other types of movement vary indefinitely. Spatially, a uniform frequency of 'full' movement is shown at the several separations. Korte's direct variation of space and time was not substantiated for the distribution of 'full' movement in the present experiment. Thus the only definite quantitative relation shown by the present data is that the -75σ temporal interval is exceptionally favorable for the arousal of apparent tactual movement.

4. On the qualitative side, the introspections show that the apparent tactual movement consists of a perceptual complex which involves at least four persistent though variable factors; the peripheral factors of (i) pressure irradiation and (ii) perseveration, and the subjective (associative) factors of (iii) visual imagery and (iv) kinæsthesis.

PERCEPTION OF RELATIVE VISUAL MOTION

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This investigation[1] deals with the perception of visual motion, as experienced through the movement of two small lights in a field of vision from which the influence of surrounding objects is excluded and from which the visibility of the subject's own body is eliminated.

The general problem suggesting this series of investigations was that of the relative influence of various characteristics of the objective situation, such as the size, shape, and intensity of the moving objects, or the speed and direction of their movement, upon the accuracy with which the movements of those objects is perceived. The specific factor here chosen is intensity,[2] the influence of changes in the relative intensity of the moving objects and of changes in their absolute intensity being studied. Our data, however, further lent themselves to an examination of the following related problems: (1) the influence of the position of the moving object, (2) the influence of the direction of movement of the moving object, (3) the influence of the direction of fixation, (4) the influence of the physical movement of the stimulating object, (5) the influence of practice, and (6) the influence of knowledge of the conditions of movement.

The work was done in a dark room, and two small, circular lights, 0.6 cm in diameter, moving in a horizontal plane at the level of the eyes of the subject, were used as moving objects.

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[1] This investigation was conducted at the Psychological Laboratory of the University of Chicago. It constitutes an extension and elaboration of a preliminary investigation with slightly different apparatus by Carr and Hardy (H. A. Carr & M. C. Hardy, Some factors in the perception of relative motion; a preliminary experiment, *Psychol. Rev.*, 1920, 28, 24–37), and is supplementary to another study, not yet published, by H. R. Mayberry with the same apparatus.

[2] The influence of form was also studied, small vertical and horizontal lights being used. This phase of the investigation will be reported separately.

The apparatus (Fig. 1) was especially designed and built for investigations in the field of visual motion. It provides for ten speeds of movement of each of the two lights; for variability of amplitude of movement of either or both lights; for eight

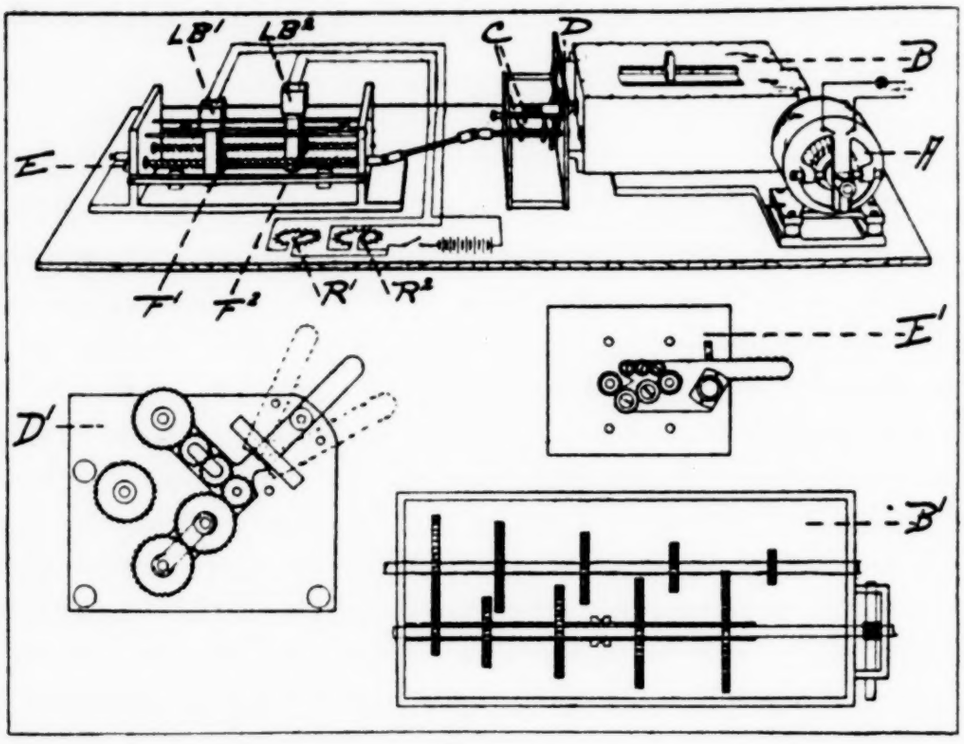

FIG. 1.

types or conditions of movement of the lights with respect to each other; for independent control of the intensities of the lights and of the length of their exposures; and for changes at will of the size or form of either light. By means of an electric motor (*A*), and the necessary gears, levers, controls, and spiral drives, the movements of two small boxes (LB^1 and LB^2) are controlled along double horizontal tracks. The boxes are 35 cm x 35 cm x 35 cm in size, and contain 2 cp electric lights. The gears within *B* (details of which are shown in B^1) make available five different speeds; by means of the gears at *C* each of these five speeds can be decreased by one half. The lever at *D* (detailed in D^1) provides for reversible direction of movement of LB^1 and LB^2; the lever at *E* (detailed in E^1) controls the direction of the movements of the boxes with respect to each other, sending them simultaneously in the same direction, or in opposite directions; and by means of release clutches at F^1 and F^2 either box can be thrown out of movement. The rheostats at R^1 and R^2 provide for the independent control of the intensities of the two lights. The face slides of the light boxes are removable, and provide for the changes of size and form of the lights. Behind the face slides, in front of the electric bulbs, are fitted frosted glass slides. The lights are fed from a storage battery. Approximately 60 cm amplitude of movement is possible.

All eight conditions of movement were utilized, as follows. Both lights moved simultaneously, at the same speed and amplitude of movement, in 50 per cent. of the cases; in 50 per cent. of the cases one light only moved. When both lights were moving, they moved in the same direction in half of the cases, moving either to the right or to the left an equal number of times; and in half of the cases they moved in

opposite directions, moving toward each other or away from each other an equal number of times. When only one light moved, in half of the cases the right light was the moving one, moving toward or away from the stationary left light an equal number of times; in the other half of the cases the left light was the moving one, moving toward or away from the stationary right light an equal number of times.

Speed, at 2 cm per sec, and length of exposure, 2 sec, were constant throughout. Thus with only one light moving, the moving light moved toward or away from the stationary light within a space of 4 cm, from a maximal divergence of 9 cm (center to center) to a maximal proximity of 5 cm. With both lights moving in divergence and convergence, the distance between them varied from greatest proximity at 5 cm to a maximal divergence at 13 cm. With both lights moving in the same direction, the distance between them remained constant at 9 cm.

Under all conditions the right light and the left light were each fixated an equal number of times.

To these various conditions subjects reacted by reporting orally whether both lights were seen as moving at the same speed or at different speeds, and if at different speeds, which light was seen as moving the faster.

It was thus possible to classify reactions on the basis of their accuracy. This was done in terms of greatest, medium and least accuracy. Greatest accuracy, when both lights were moving at the same speed and they were so reported; or when one light only was moving and it was reported as moving the faster. Medium accuracy, when both lights were moving at the same speed, and either one was reported as moving the faster; or when one light only was moving, and they were reported as moving at the same speed, or as both being stationary. Least accuracy, when both lights were moving at the same speed and they were reported as being stationary; or when one light only was moving, and the stationary light was reported as moving the faster.

All reactions to any one condition were thus classified, and the percentage frequencies tabulated for greatest, medium, and least accuracy. For example, for the condition both lights at equal intensity, moving at the same speed and amplitude in the same direction, the percentage frequencies were determined with which the lights were reported as moving at the same speed, or as being stationary, or either light was reported as moving the faster. Next, a similar tabulation was made of a related condition, in which the factor of intensity only was changed. For example, as before, for the condition both lights moving at the same speed and amplitude and in the same direction, but the lights now of unequal intensity, the one at the left (let us say) being the dimmer. The two distributions were then statistically compared. To the extent that differences were found, and to the extent that these differences were so large as to preclude the accidents of chance, they were attributed to the influence of the factor of intensity.

Three different degrees of intensities were used, minimal, medium, and maximal. The minimal approximated the limen of visibility; the maximal was the greatest possible without illuminating the room; and the medium was approximately a mean of the sense difference between the minimum and the maximum. All permutations of these intensities were used, as follows:

minimum—minimum,
medium—medium,
maximum—maximum,
minimum—medium,
minimum—maximum,

medium—minimum,
medium—maximum,
maximum—minimum, and
maximum—medium.

These nine combinations of intensities, together with the eight conditions of movement, with right and left fixation, gave 144 conditions. To these 144 conditions, forty-four subjects, students in the Department of Psychology, contributed a total of 201,600 reactions. Ten reactions to each of the 144 conditions were secured from each of thirty-seven subjects. Three subjects each contributed a total of 18,720 reactions, three subjects each a total of 20,160 reactions, and one subject a total of 21,600 reactions. Each of these seven contributed an additional 1,440 reactions to the same conditions with full knowledge.

The general form of procedure may be outlined as follows. Upon entering the dark room the subject took his seat three meters distant from the lights (which were concealed from his view by a heavy curtain), with his line of vision at right angles to the direction of movement. The room was then darkened, and a period of adaptation followed, varying from five to ten minutes with the individual subjects, the ability to see the lights at minimal intensity being the customary criterion. A condition was then presented to the subject, *i.e.* the lights were thrown on and into motion simultaneously, remaining on and in motion for two seconds. The subject's reaction was then reported orally, and was recorded by the experimenter. Then followed another condition. The conditions were presented in random order, the number given during the hour the subject was in the dark room depending upon the quickness of response. A metronome was used to time the duration of exposures. All recording was done in the dark, on an endless record, with the aid of a memory drum.

Observed proportions were treated as percentage frequencies. The two formulæ which were utilized for statistical evaluation of the significance of the results are both from Yule. $s^2 = pq/n$, the standard error of the proportion, for evaluating the significance of an observed proportion. $E_{12}^2 = p^1q^1/n^1 + p^2q^2/n^2$, the standard error of the difference between two samplings, for testing the significance of the observed differences. As convenient bases of evaluation of our data, observed proportions are arbitrarily treated as significant when they exceed the theoretical proportions by

three times the difference between them; and differences between observed proportions are treated as significant when the differences exceed the S.E.s of those differences by three times or more.

In the tables of observed proportions which follow, the percentage frequencies of greatest accuracy (GA), medium accuracy (MA), and least accuracy (LA) are given.[3] These tables constitute the factual sources of information from which conclusions are derived with respect to the extent to which specific factors function to influence the accuracy of the perception of motion under the conditions of this investigation.

Intensity

The light intensity or brightness of the stimulating object or objects employed in inducing an experience of perceived visual motion has been recognized as an important factor by those who have carried on investigations in this field. Carr and Hardy,[4] in their preliminary study, concluded that both relative intensity and absolute intensity were factors; that perceptual accuracy was a function both of inequality of intensity and of increased absolute intensity. Adams[5] reports Exner and Bourdon as having found that feebleness of intensity favored movement in the autokinetic illusion. And Korte[6] has given definite expression to the importance of intensity in securing optimal movement in the phi-phenomenon in his formulation of the laws governing such movement.

The problem in the case of the autokinetic illusion is primarily one of absolute intensity, since a single stimulating object is used. In the case of the phi-phenomenon it is both absolute and relative. For example, increasing the intensity

[3] In the original manuscript, on file in the Library of the University of Chicago, the s's of the theoretical proportions are included in all tables of observed proportions. That manuscript also contains a complete series of tables giving the differences between observed proportions of reactions to the varied aspects of specific factors, the standard errors of those differences, and the extent to which the differences exceed the standard errors.

[4] *Op. cit.*

[5] H. F. Adams, Autokinetic sensations, *Psychol. Monog.*, 1912, 14 (no. 59).

[6] A. Korte, Kinematoskopische Untersuchungen, *Zsch. f. Psychol.*, 1915, 72, 193–296.

of the stimuli (increased absolute intensity) necessitates an increase in the distance between the stimuli ($i_{opt} \sim s$), or a decrease in the time of their exposure ($i_{opt} \sim I/t$), in order to secure optimal movement. In delta movement the relative intensity of the stimuli determines the initial direction of movement toward the weaker stimulus.

Thus relative intensity and absolute intensity constitute two separate, although not necessarily independent, problems. To determine whether they both influence perceptual accuracy of movement, as Carr and Hardy were inclined to conclude, or augment or limit perceived movement as such, as in the phi-phenomenon, was a primary purpose in the organization of this experiment.

Relative Intensity

Although our procedure was designed to control relative intensity in order that it might be isolated and its influence studied separately, other inherent factors persisted to complicate the interpretation of results.

Under all conditions of inequality of intensity the dimmer light appeared to be the smaller one, and to be more distant than the bright light. Satisfactory explanations of the factual bases of both of these phenomena are common. But the same is not true of their respective influences upon perceived motion. An object with a given amplitude of movement is seen as moving through a greater extent of space in proximity than at a distance. The explanation in terms of the angle of projection is obvious. On this basis the bright light, with the apparently greater amplitude of movement in a given time, should be seen as moving the faster. But the speed of movement of a near object results in a blurring of the retinal image, and this indistinctness becomes a criterion of speed. And on the basis of its greater indistinctness the dim light should possess the greater mobility.

Holding in abeyance our evaluation of the respective influences of size and of the apparent difference in distance of the two lights, we shall interpret our data in terms of relative intensity.

With Only One Light Moving. Table I provides for comparisons of the observed proportions of greatest accuracy (GA), medium accuracy (MA), and least accuracy (LA) when the lights were of equal intensity, only one light moving, with

TABLE I

OBSERVED PROPORTIONS UNDER CONDITIONS OF RELATIVE INTENSITY

Subjects	Equal Intensities			Unequal Intensities					
				Bright Light Moving			Dim Light Moving		
	GA	MA	LA	GA	MA	LA	GA	MA	LA
(37)[3]	46	35	19	36	35	29	54	31	15
G	51	19	30	44	17	39	61	17	22
Mi	51	04	45	47	06	47	53	08	39
Mo	23	73	04	03	21	76	91	08	01
P	47	19	34	24	32	44	52	34	14
Sh	37	39	24	35	36	29	51	27	22
St	51	13	36	44	09	47	70	08	22
Y	49	23	28	21	28	51	70	17	13
(7)	44	27	29	31	21	48	64	17	19

Only one light moving. Both right and left fixations. Four directions of movement.

the observed proportions of GA, MA, and LA when the lights were of unequal intensity and the bright light was the moving one; for comparisons of the observed proportions when the lights were of equal intensity with the observed proportions when the lights were of unequal intensity and the dim light was the moving one; and for comparisons of the observed proportions when the bright light was the moving one with the observed proportions when the dim light was the moving one.

Comparing the observed proportions when the lights were of equal intensity with the observed proportions when the lights were of unequal intensity and the bright light was moving shows, in every instance, decreased accuracy with inequality of intensity, and, of equal significance, increased inaccuracy in every instance. Only in two cases (Sh in GA,

[3] The combined records of the thirty-seven subjects from each of whom ten reactions were secured to each of the 144 conditions, are given mass treatment throughout, and appear in the tables as "(37)." The "(7)" is the average for the seven from each of whom approximately twenty thousand reactions were secured, and whose individual records appear in the tables as G, Mi, Mo, *etc.*

and Mi in LA) are those differences so small that they may have been due to the accidents of chance.

A similar comparison of the observed proportions when the lights were of equal intensity with the observed proportions when the lights were of unequal intensity and the dim light was moving shows, in every instance, increased accuracy and decreased inaccuracy with inequality of intensity. And again in all but two cases (Mi in GA, and Sh in LA) these differences are so large as to preclude the accidents of chance.

The greater frequency with which the dim light was seen as moving the faster is still more apparent if the results when the bright light was the moving one are compared with the results when the dim light was the moving one. Not only are the differences between the frequency with which the dim light was seen as moving the faster when it alone moved and the frequency with which the bright light was seen as moving the faster when it alone moved so great as to exceed the S.E.s of those differences by from five to more than 150 times, but in all but three instances (G, Sh, and the average for the thirty-seven) the frequency with which the dim stationary light was reported as moving the faster equalled or exceeded the frequency with which the bright moving light was so reported.

In general, medium accuracy with lights of equal intensity exceeded medium accuracy with lights of unequal intensity. The exceptions show, for two subjects (Mi and P), greater medium accuracy with inequality of intensity, irrespective of whether the dim light or the bright light was moving, and for one subject (Y) greater medium accuracy when the bright light was the moving light.

Since the observed proportions for the bright light moving and the dim light moving represented totals for inequality of one degree of difference (minimum-medium, and medium-maximum) and for two degrees of difference (minimum-maximum), the data were further examined in order to note the influence of varying degrees of inequality of intensity upon the accuracy with which the situation was perceived. Table II provides for an examination of the results when the bright light was moving; Table III when the dim light was moving.

TABLE II

OBSERVED PROPORTIONS UNDER CONDITIONS OF RELATIVE INTENSITY

Subjects	Equal Intensities			Unequal Intensities					
				One Degree of Difference			Two Degrees of Difference		
	GA	MA	LA	GA	MA	LA	GA	MA	LA
(37)....	46	35	19	37	36	27	33	33	34
G.....	51	19	30	45	19	36	43	14	43
Mi.....	51	04	45	47	06	47	45	07	48
Mo.....	23	73	04	03	26	71	01	11	88
P.....	47	19	34	27	31	42	18	35	47
Sh.....	37	39	24	35	39	26	37	31	32
St.....	51	13	36	47	07	46	38	12	50
Y.....	49	23	28	26	29	45	12	25	63
(7).....	44	27	29	33	22	45	28	19	53

Only bright light moving. Both right and left fixations. Four directions of movement.

TABLE III

OBSERVED PROPORTIONS UNDER CONDITIONS OF RELATIVE INTENSITY

Subjects	Equal Intensities			Unequal Intensities					
				One Degree of Difference			Two Degrees of Difference		
	GA	MA	LA	GA	MA	LA	GA	MA	LA
(37)....	46	35	19	52	33	15	60	27	13
G.....	51	19	30	68	18	14	69	14	17
Mi.....	51	04	45	52	08	40	55	07	38
Mo.....	23	73	04	88	11	01	95	04	01
P.....	47	19	34	50	33	17	56	35	09
Sh.....	37	39	24	49	28	23	55	24	21
St.....	51	13	36	66	10	24	77	04	19
Y.....	49	23	28	65	20	15	79	13	08
(7).....	44	27	29	63	18	19	69	14	17

Only dim light moving. Both right and left fixations. Four directions of movement.

An examination of those tables shows that from equal intensity, through inequality of one degree of intensity to inequality of two degrees of intensity, with the bright light moving, there was an increasing tendency toward decreased accuracy and toward increased inaccuracy; with the dim light moving there was an increasing tendency toward increased

accuracy and toward decreased inaccuracy. In general there was an increasing tendency toward decreased medium accuracy, the only exceptions beside those in the records of Mi, P, and Y being in the records of St, and the average for the thirty-seven.

Thus with one light moving, inequality of intensity was conducive to accuracy when the dim light was the moving light, to inaccuracy when the bright light was moving, and to decreased medium accuracy irrespective of whether the bright light or the dim light was moving. If expressed in terms of movement instead of accuracy, the results may be stated as follows. Inequality of intensity of the two lights was conducive to inequality of their mobility; to greater mobility of the dimmer light and to decreased mobility of the brighter; and the degree of mobility of each light was roughly proportional to the degree of inequality of their intensities.

Both Lights Moving. The observed proportions of reactions of greatest accuracy, medium accuracy, and least accuracy, when both lights were moving, are given in Table IV, and provide for a comparison of the results when the lights were of equal intensity with the results when the lights were of unequal intensity.

TABLE IV

OBSERVED PROPORTIONS UNDER CONDITIONS OF RELATIVE INTENSITY

Subjects	Equal Intensities			Unequal Intensities			
	GA	MA	LA	GA	MA		LA
					Bright	Dim	
(37)	42	42	16	39	18	26	17
G	22	73	05	23	27	46	04
Mi	09	78	13	09	31	46	14
Mo	60	16	24	25	02	44	29
P	48	26	26	33	07	24	36
Sh	39	50	11	40	24	31	05
St	08	88	04	09	30	55	05
Y	31	56	13	24	14	47	15
(7)	31	55	14	24	19	42	15

Both lights moving. Both right and left fixations. Four directions of movement.

An examination of this table shows significantly decreased accuracy with inequality of intensity for the thirty-seven, for three subjects (Mo, P, and Y), and for the average for the seven; and an insignificant increase (of 01) for three subjects (G, Sh, and St). With two exceptions (G and Sh), only one of which is significant (Sh), inequality of intensity resulted in increased inaccuracy. The frequency with which the dim light was seen as moving the faster exceeds the MA mean with the lights at equal intensity in every instance; while the frequency with which the bright light was seen as moving the faster is less than the MA mean with the lights at equal intensity in every instance. And with one exception (Sh) these differences are all sufficiently large to be significant.

A progressive comparison, Table V, through inequality of one degree of difference (minimum-medium, medium-maximum) to inequality of two degrees of difference (minimum-maximum) shows that the degree of variation is roughly proportional to the degree of inequality of intensity. With increasing inequality of intensity there is an increasing

TABLE V

OBSERVED PROPORTIONS UNDER CONDITIONS OF RELATIVE INTENSITY

Subjects	Equal Intensities			Unequal Intensities							
				One Degree of Difference				Two Degrees of Difference			
	GA	MA	LA	GA	MA		LA	GA	MA		LA
					Br	Dim			Br	Dim	
(37)	42	42	16	40	18	25	17	37	18	29	16
G	22	73	05	25	29	42	04	21	23	50	06
Mi	09	78	13	10	32	44	14	08	30	48	14
Mo	60	16	24	27	01	44	28	21	01	46	32
P	48	26	26	37	06	23	34	29	06	27	38
Sh	39	50	11	42	24	29	05	37	25	33	05
St	08	88	04	09	31	54	05	09	25	61	04
Y	31	56	13	27	15	42	16	20	10	55	15
(7)	31	55	14	25	20	40	15	21	17	46	16

Both lights moving. Both right and left fixations. Four directions of movement.

tendency toward decreased greatest accuracy, toward increasing inaccuracy, toward decreasing frequency with which

the bright light is seen as moving the faster, and toward increasing frequency with which the dim light is seen as moving the faster.

The relative frequency with which the bright light and the dim light were each perceived as moving the faster may be seen by referring back to Tables IV and V. Without an exception the dim light was seen as moving faster more frequently than the bright light was so perceived. The differences are all large, exceeding the S.E.s of those differences by from eight to more than sixty times.

Thus with both lights moving, inequality of intensity functioned to decrease accuracy, to increase inaccuracy, to decrease the frequency with which the bright light was seen as moving the faster, and to increase the frequency with which the dim light was seen as moving the faster. In other words, as with one light moving, inequality of intensity of the two lights was conducive to inequality of their mobility; to greater mobility of the dim light and to decreased mobility of the bright light; and the degree of mobility of each light was roughly proportional to the degree of inequality of their intensity.

Absolute Intensity

Although in modified form, the same incidental factors which were present to interfere with complete isolation of relative intensity also prevented complete isolation of absolute intensity. Increasing the intensity of the lights made them appear to be nearer and larger; decreasing their intensity made them appear to be more distant and smaller. Although these variations in apparent size and distance probably were small as compared with the changes in intensity, still in drawing conclusions from our results they must be recognized as being present as potential factors.

One Light Moving. With one light moving, our data lent themselves to a comparison (1) of the results under three conditions of equal intensity, as both lights at equal minimal intensity, both lights at equal medium intensity, and both lights at equal maximal intensity; and (2) of the results under two conditions of unequal intensity, viz., the lights at mini-

mum-medium intensities, and the lights at medium-maximum intensities.

Table VI gives the observed proportions of greatest accuracy, medium accuracy, and least accuracy under conditions

TABLE VI

OBSERVED PROPORTIONS UNDER CONDITIONS OF ABSOLUTE INTENSITY

Subjects	Minimum			Medium			Maximum		
	GA	MA	LA	GA	MA	LA	GA	MA	LA
(37)	46	34	20	46	35	19	45	36	19
G	51	19	30	51	19	30	52	19	29
Mi	52	05	43	51	03	46	51	03	46
Mo	20	77	03	24	71	05	25	72	03
P	45	24	31	47	17	36	48	17	35
Sh	44	26	30	39	35	26	27	57	16
St	50	15	35	51	13	36	51	10	39
Y	52	24	24	50	20	30	46	24	30
(7)	45	27	28	45	25	30	43	29	28

Both lights of equal intensity. Only one light moving. Both right and left fixations. Four conditions of movement.

of equal minimal intensity, equal medium intensity, and equal maximal intensity.

An examination of this table shows significant differences in greatest accuracy to be the exception. Nor do such differences as consistently appear parallel variations in absolute intensity. In the one instance, however, in which there is a significant variation (Sh) there is a consistent decrease in accuracy with increase in absolute intensity.

Neither is there any consistent variation in least accuracy. In the two instances in which there appear statistically significant variations, in one case (Sh) there was decreased inaccuracy, and in the other case (Y) there was increased inaccuracy with increased absolute intensity.

Medium accuracy provides the most marked variations. The subject (Sh), whose record shows that with greater absolute intensity there was a decreasing tendency to see either light as moving the faster, showed an increase in medium accuracy. The other two variations (for Mo and P) sufficiently large to be significant show less medium accuracy with greater absolute intensity.

The most striking characteristic of the results under conditions of inequality of intensity (Table VII) is the consistent tendency toward increased accuracy and toward decreased inaccuracy when the bright light was moving, and toward decreased accuracy and increased inaccuracy when the dim light was moving, under conditions of greater absolute intensity; although, in general, the differences are not sufficiently large to be statistically significant. Only two

TABLE VII

OBSERVED PROPORTIONS UNDER CONDITIONS OF ABSOLUTE INTENSITY

Subjects	The Bright Light Moving						The Dim Light Moving					
	Medium-Minimum			Maximum-Medium			Minimum-Medium			Medium-Maximum		
	GA	MA	LA	GA	MA	LA	GA	MA	LA	GA	MA	LA
(37).....	38	32	30	36	40	24	57	28	15	46	38	16
G.....	43	18	39	47	20	33	60	17	23	55	19	26
Mi.....	47	06	47	48	05	47	52	08	40	52	08	40
Mo.....	03	23	74	04	29	67	89	11	00	88	11	01
P.....	23	36	41	31	26	43	50	34	16	50	33	17
Sh.....	38	32	30	31	46	23	53	23	24	46	33	21
St.....	45	08	47	49	06	45	68	05	27	64	15	21
Y.....	23	31	46	29	27	44	69	18	13	61	21	18
(7).....	32	22	46	34	23	43	63	17	20	59	20	21

The lights of unequal intensities. Only one light moving. Both right and left fixations. Four directions of movement.

sig ificant exceptions (Sh, the bright light moving; and St, the dim light moving) to this general tendency appear. In other words, with greater absolute intensity when the lights were of unequal intensity, there was a decrease in the frequency with which the dim light was seen as moving the faster, and an increase in the frequency with which the bright light was seen as moving the faster, *i.e.* there was a decrease in the inequality of mobility of the two lights. This is further verified by a reference to the observed proportions of medium accuracy; with but four exceptions, only one of which is significant (P, bright light moving), increased absolute intensity resulted in increased medium accuracy.

Both Lights Moving. With both lights moving the data

also permitted a comparison of the results under three conditions of absolute intensity when the lights were of equal intensity, viz., both lights at minimal intensity, both lights at medium intensity, and both lights at maximal intensity (Table VIII); and under two conditions of inequality of

TABLE VIII

OBSERVED PROPORTIONS UNDER CONDITIONS OF ABSOLUTE INTENSITY

Subjects	Minimum			Medium			Maximum		
	GA	MA	LA	GA	MA	LA	GA	MA	LA
(37)....	44	42	14	41	44	15	41	41	18
G.....	16	74	10	25	73	02	25	72	03
Mi.....	10	77	13	08	80	12	09	77	14
Mo.....	59	15	26	61	15	24	58	19	23
P.....	47	22	31	48	28	24	50	28	22
Sh.....	27	59	14	48	49	03	41	43	16
St.....	12	83	05	06	90	04	06	92	02
Y.....	27	57	16	28	58	14	37	53	10
(7).....	28	55	17	32	56	12	32	55	13

Both lights of equal intensity. Both lights moving. Both right and left fixations. Four conditions of movement.

TABLE IX

OBSERVED PROPORTIONS UNDER CONDITIONS OF ABSOLUTE INTENSITY

Subjects	Minimum-Medium				Medium-Maximum			
	GA	MA		LA	GA	MA		LA
		Br	Dim			Br	Dim	
(37).....	40	19	25	16	41	17	24	18
G.....	23	30	44	03	26	29	41	04
Mi.....	10	31	46	13	09	33	43	15
Mo.....	23	01	46	30	.31	02	41	26
P.....	37	06	23	34	36	07	24	33
Sh.....	38	25	33	04	46	23	25	06
St.....	07	32	57	04	12	31	51	06
Y.....	26	15	44	15	27	16	40	17
(7).....	23	20	42	15	27	20	38	15

The lights of unequal intensities. Both lights moving. Both right and left fixations. Four conditions of movement.

intensity, viz., minimum-medium and medium-maximum intensities (Table IX). The outstanding characteristics of the results, as shown by these tables, are (1) the absence of any

consistent tendency in the variations which appear, and (2) the fact that a large majority of the variations are so small as to be statistically insignificant.

On the basis of such variations as appear, irrespective of whether these variations are sufficiently large to be significant, it may be said that increased absolute intensity was conducive to perceptual accuracy in the case of five subjects when the lights were of equal intensity, and of six subjects when the lights were unequal in intensity; that it was conducive to decreased inaccuracy with five subjects when the lights were equal in intensity, and with two subjects when the lights were unequal in intensity; that it was conducive to decreased frequency with which the dim light was seen as moving the faster; and that three subjects showed increased medium accuracy under the same conditions when the lights were of equal intensity. And in spite of the differences, the averages for the seven confirm these tendencies, with two exceptions: in the case of medium accuracy, lights of equal intensity, there is an increase (of 01) only with the lights at medium intensity, and in the case of least accuracy, lights of unequal intensity, there is no change. For the thirty-seven subjects, however, the averages show decreased accuracy with the lights of equal intensity, increased least accuracy under conditions of both equal and unequal intensity, and an increase, then a decrease in medium accuracy.

If the results be interpreted on the basis of variations sufficiently large to be statistically significant, it may be said that, when the lights were equal in intensity, increased absolute intensity functioned to increase perceptual accuracy in the case of three subjects (G, Sh, and Y), and to decrease perceptual accuracy in the case of one subject (St); when the lights were unequal in intensity, it functioned to increase perceptual accuracy in the case of three subjects (Mo, Sh, and St); and, when the lights were equal in intensity, it functioned to decrease inaccuracy with three subjects (G, P, and Sh). It functioned to decrease medium accuracy in the case of one subject (Sh), and to increase medium accuracy with two subjects (P and St); and it functioned to decrease the

frequency with which the dim light was seen as moving the faster with three subjects (Mo, Sh, and St). And changes in the averages for the seven, sufficiently large to be significant, confirm these tendencies in all cases except in medium accuracy. Variations in the averages for the thirty-seven are not large enough to be significant.

Although it may be hazardous to formulate any general conclusions from results showing no more consistency than these, either with one light moving or with both lights moving, it may be said that increased absolute intensity functions to increase equality of mobility of the two lights. This may be seen in decreased inequality of mobility, when the lights were of unequal intensity; decreased frequency with which either light was seen as moving the faster (GA, one light moving; MA, both lights moving); and increased frequency with which both lights were seen as moving at the same speed (GA, both lights moving; MA, one light moving). In general, however, variations were small, and in view of this absence of significant differences, it may be as legitimate to conclude that *variations in absolute intensity exert but a slight influence, if any, upon perceptual accuracy of movement.*

Discussion of Results

Thus under the conditions of our experiment, as in the autokinetic illusion, feebleness of intensity favored movement. And inequality of intensity was found to be a factor influencing perceptual accuracy, as Carr and Hardy concluded, but absolute intensity was not.

When our findings are compared with those reported in connection with the phi-phenomenon, there are two respects in which differences apparently exist. (1) Korte found, as reported above, that in delta movement the intense light was the more mobile, moving toward the weaker light, and then back to its original position. Our results established the greater mobility of the dim light under all conditions. (2) In the phi-phenomenon changes in absolute intensity are inseparable from changes in other factors in order to secure optimal movement. We found changes in absolute intensity exerting no appreciable influence upon perceived movement.

In the case of (2), differences probably may be explained in terms of the differences of the stimulating situations. In the phi-phenomenon optimal movement is secured by means of intermittent stimulation of adjacent retinal areas, the distance between these areas being determined by the intensity of the stimuli, and by the temporal interval of their presentation. In our investigation stimulation was continuous and hence such movement as was perceived should be independent of the extent of the retinal area involved, and of the temporal factor. This was what we found.

In the case of (1), a satisfactory explanation is more difficult. Parsons,[7] reviewing the investigations which have been conducted in the field, points out that certain electrical, chemical, and structural changes accompany stimulation of the retina, the nature of these changes being determined by the nature, intensity, and duration of the stimulus. Changes resulting from a brief stimulation of the retina, with a light of strong intensity, are quantitatively equivalent to those resulting from a longer stimulation, properly timed, with the same light at a lower intensity. Then with successive stimulations, with lights of unequal intensity, but of the same temporal duration, retinal changes and their persistence should be in proportion to the relative intensity of the lights. This would appear to be of especial importance in the interpretation of the delta movement. The phi-phenomenon is secured by a proper coördination of the intensities of the stimuli, their temporal presentation, and the adjacence of the retinal areas stimulated. The experienced movement is in the direction of the less impressive stimulus, which has produced less effective retinal changes, and then back to the more impressive stimulus, the retinal changes of which are more persistent. In this return movement the less impressive stimulus may accompany the more impressive. Thus the bright light, which has induced the more effective and persistent changes in the retinal areas stimulated, may be regarded as the stable, and the dim light, due to slighter retinal changes, may be

[7] J. H. Parsons, An introduction to the study of colour vision, 1915, Chap. II.

regarded as the more mobile. And thus interpreted there is complete accord between our results and the phi-phenomenon.

Position of the Moving Light

Carr and Hardy examined their data with respect to the influence of the position of the moving light; but since in their apparatus one light was placed above the other, rather than in a horizontal relationship, as in ours, no relevant basis exists for comparison of the results.

The organization of our experiment lent itself readily to an examination of the relative influence of positional movement, *i.e.* to a comparison of the results when the moving light was at the right with the results when the moving light was at the left. Tabulation of the data showing the percentage frequencies of greatest accuracy, medium accuracy, and least accuracy under these conditions, with one light moving, is given in Table X.

Table X

Observed Proportions for Varied Positional Movement

Subjects	Right Light Moving			Left Light Moving		
	GA	MA	LA	GA	MA	LA
(37)	44	36	20	46	32	22
G	29	22	49	77	14	09
Mi	53	08	39	47	05	48
Mo	41	33	26	38	35	27
P	46	34	20	35	24	41
Sh	43	33	24	41	34	25
St	45	07	48	64	13	23
Y	61	21	18	33	24	43
(7)	45	23	32	48	21	31

Only one light moving. Both right and left fixations. Four conditions of movement. Nine combinations of intensities.

Five of the seven subjects perceived the situation more accurately when the right light was moving. With one exception (Sh), the differences are all sufficiently large to be significant.

But equally significant are the records of the two subjects (G and St) for whom the moving light at the left was conducive to perceptual accuracy. In one case (St) the difference exceeds the S.E. of the difference by more than twenty times, and in the other case (G) by more than fifty-three times.

That there is individual constancy in this susceptibility toward perception of positional movement is suggested by the definite parallelism that exists between the GA and the LA proportions. A higher GA proportion with the right light moving, for example, is paralleled with a higher LA proportion (illusory movement of the right stationary light) with the left light moving, and *vice versa*. In other words, the tendency to see either light as moving the faster persists, whether that movement is based upon the physical movement of the perceived object or is illusory.

That there may be some relationship between susceptibility to right or left movement and right- or left-handedness is suggested by the fact that the subject (G) who showed the most marked sensitiveness to movement at the left is definitely left-handed. Such a relationship, if it can be established, will be in complete accord with the findings of Parsons.[4]

Direction of Movement

The investigations dealing with the autokinetic and the stroboscopic phenomena have included an examination of the visual tendencies toward perceived directions of movement. In his work with the autokinetic illusion, Carr found that when fixating the light directly the movement was irregular;[5] while Lindemann's results[6] suggested that horizontal movement exceeds vertical. Although in our experiments movement was confined to the horizontal plane, it did permit an examination of the influence of the direction of movement upon the accuracy with which that movement was perceived.

A comparison of the results when the moving light was moving to the right and to the left shows (Table XI), with one exception, greater perceptual accuracy when the movement was to the left. And this apparently greater suggestibility of movement to the left persisted in a greater tendency toward perceived illusory movement in the same direction. Thus when the moving light actually was moving to the right,

[4] B. S. Parsons, *Lefthandedness; a new interpretation*, (Macmillan), 1924.

[5] H. A. Carr, The autokinetic sensation, *Psychol. Rev.*, 1910, 17, 42–75.

[6] E. Lindemann, *op. cit.*

toward or away from the stationary light, the frequency with which the stationary light was seen as moving the faster to the

TABLE XI

OBSERVED PROPORTIONS UNDER VARIED DIRECTIONS OF MOVEMENT

Subjects	Movement to the Right			Movement to the Left		
	GA	MA	LA	GA	MA	LA
(37)	42	34	24	48	33	19
G	50	15	35	55	20	25
Mi	47	05	48	53	06	41
Mo	41	32	27	37	36	27
P	36	28	36	46	29	25
Sh	29	37	34	53	31	16
St	54	09	37	56	11	33
Y	46	23	31	48	23	29
(7)	43	21	36	50	22	28

One light moving. Both right and left fixations. Four directions of movement. Nine combinations of intensities.

left, toward or away from the other light, exceeds the frequency with which the stationary light was seen as moving the faster to the right when the other light actually was moving to the left.

Whether this greater tendency to perceive movement to the left may be due to anisotropic conditions of the retina, or to kinæsthesia contingent upon habitual activity, we are not prepared to say. Such peculiarities of habitual activity as are involved in the reading process suggest an explanation. The eyes, being accustomed to the inhibitions incident to span of perception in following the line across the printed page, would be less sensitive to inhibitions of controlled movement to the right, and less sensitive to movement to the right than to movement to the left under such conditions as prevailed in this investigation.

FIXATION

Carr and Hardy were unable to come to any final decision as to the influence upon perceptual accuracy of fixation of the moving light as opposed to fixation of the stationary light. Their results did not consistently favor either mode of fixation, and such differences as did appear were not large enough to be

significant. Investigators in the field of the phi-phenomenon report both attention and fixation as being important factors, the former facilitating it (Schumann),[7] and the latter destroying it in the gamma movement (Lindemann).[8] In our investigation attention was extended to the whole field of vision in the sense that all subjects attended to both lights. Fixation, on the other hand, was restricted at all times to a particular light. As a result our procedure was calculated to isolate that factor.

In order to show the influence of fixation, a twofold treatment of our data was employed; (1) as showing the influence of the direction of fixation, *i.e.* fixation of the right (or left) light, and (2) as showing the influence of fixation as opposed to that of non-fixation.

Right Fixation vs. Left Fixation. Table XII gives a classification of all reactions in terms of greatest accuracy, medium accuracy, and least accuracy when the right or left light was fixated. The averages for the thirty-seven and for the seven show slightly greater medium accuracy, and less accuracy (GA) and inaccuracy (LA) when the left light was fixated; but the differences are all extremely small. Such variations as appear in the records of the individual subjects are in general so small as to have no

TABLE XII

OBSERVED PROPORTIONS FOR VARIED DIRECTIONS OF FIXATION

Subjects	Fixation of the Right Light			Fixation of the Left Light		
	GA	MA	LA	GA	MA	LA
(37)	43	38	19	43	39	18
G	38	46	16	38	44	18
Mi	30	40	30	31	42	27
Mo	38	36	26	37	34	29
P	41	25	34	38	33	29
Sh	42	43	15	41	45	14
St	39	48	13	28	49	23
Y	38	36	26	37	46	17
(7)	38	39	23	36	42	22

All eight conditions of movement. Nine combinations of intensities.

[7] F. Schumann, Beiträge zur Analyse der Gesichtswahrnehmung, *Zsch. f. Psychol.*, 1902, 30, 241–291.

[8] E. Lindemann, *op. cit.*

statistical significance, and they show no consistency as favoring either fixation.

Fixation vs. Non-fixation. The classification of observed proportions under conditions of fixation and non-fixation is given in Table XIII. That table provides for a comparison of the results when the moving light was fixated with the results when the stationary light was fixated; and for a comparison of the frequency with which the fixated light was seen as moving the faster with the frequency with which the light moving in indirect vision was seen as moving the faster, when both lights were moving at the same speed.

TABLE XIII

OBSERVED PROPORTIONS WITH DIRECT AND INDIRECT VISION

Subjects	One Light Moving						Both Lights Moving	
	Fixating the Moving Light			Fixating the Stationary Light			Fixated Light	Non-fixated Light
	GA	MA	LA	GA	MA	LA		
(37)	49	34	17	41	34	25	24	20
G	53	18	29	51	18	31	30	43
Mi	96	03	01	04	09	87	64	12
Mo	47	33	20	31	36	33	22	14
P	78	20	02	04	37	59	27	03
Sh	41	34	25	41	35	24	27	27
St	94	04	02	16	13	71	78	09
Y	67	21	12	22	24	54	43	16
(7)	68	19	13	24	25	51	42	17

Both right and left fixations. Nine combinations of intensities. Four directions of movement for each light moving, and for both lights moving.

When one light only was moving, perceptual accuracy, when fixating the moving light, exceeded perceptual accuracy when fixating the stationary light, with one exception (Sh), and in that instance there was no change. And this greater tendency to perceive the fixated light as moving the faster prevailed in perceived illusory movement. The frequency with which the stationary light was reported as moving the faster when that light was fixated exceeded the frequency with which that light was reported as moving the faster in indirect vision, with one exception (Sh), and in that case the difference

was so small that it may be attributed to the accidents of chance. This conduciveness of fixation to mobility is further attested by the increased frequency with which the lights were seen as moving at the same speed when the stationary light was the one fixated.

With both lights moving at the same speed, there were but two exceptions (G and Sh) to the greater frequency with which the fixated light was seen as moving the faster. In one of those cases (Sh) there was no difference. In the other case, however, the difference is so large there can be no question of a high degree of susceptibility to movement in indirect vision. A reference to that subject's record under conditions of one light moving, irrespective of which light was fixated, shows the highest scores for perceived movement in indirect vision. Thus for that subject it was a consistent tendency.

From these results it would appear that direction of fixation, as fixation of the right *vs.* fixation of the left, exerts no appreciable influence upon the accuracy with which the objective situation is perceived. But that fixation induces mobility of the object fixated appears definitely established.

Physical Movement

That the physical movement of the object facilitates perceived movement of that object, both in direct and indirect vision, may be seen by referring back to Table XIII.

A comparison of the frequency with which the fixated light was seen as moving the faster, when that light only was moving (GA), with the frequency with which the fixated stationary light was seen as moving the faster (LA) shows, in the latter, decreased frequency of reported movement in every instance. A similar comparison of the frequencies with which the moving light (GA) and the stationary light (LA) were seen as moving the faster in indirect vision shows (also in every instance) decreased frequency in the latter of greater apprehended movement. And without an exception all the differences are sufficiently large to be significant.

This seems of importance to the writer in view of the assertions that have been appearing in the literature in

connection with the stroboscopic movement that there is no difference between perceived physical movement and perceived illusory movement.

It is difficult to account for the differences we found unless they be attributed to the influence of the physical movement of the perceived object. Both in direct and indirect vision, probably more particularly in indirect vision, this may be due to the streaming phenomenon. But in addition, when fixating the moving light, may there not be functioning some phase of the pursuit movement? [9]

Practice

The conditions governing our procedure were such as to keep the subject ignorant of the accuracy or inaccuracy of his reactions. In order to determine whether, under these conditions, practice functioned to increase accuracy, a progressive comparison was made of the records of the seven subjects each of whom served one hour daily for about six weeks and each of whom contributed about twenty thousand reactions. For this comparison the first 2880, the middle 2880, and the last 2880 reactions were used. These are tabulated in Table XIV.

Table XIV

Observed Proportions at Different Periods

Subjects	At the Beginning			Midway			At the Close		
	GA	MA	LA	GA	MA	LA	GA	MA	LA
G.....	41	41	18	38	45	17	39	46	15
Mi.....	36	38	26	32	40	28	33	40	27
Mo.....	42	39	19	38	35	27	38	30	32
P.....	38	30	32	41	29	30	39	30	31
Sh.....	38	44	18	39	44	17	41	52	07
St.....	34	44	22	35	48	17	36	46	18
Y.....	35	42	23	38	41	21	40	38	22

All eight conditions of movement. Nine combinations of intensities. Both right and left fixations.

Three subjects (G, Mi, and Mo) showed decreased accuracy, and two of those three (Mi and Mo) increased least-

[9] R. Dodge, The participation of the eye movements in the visual perception of motion, *Psychol. Rev.*, 1904, 11, 1–14.

accuracy, as the investigation progressed; while the other four showed increased greatest-accuracy, and decreased least-accuracy. Two subjects (Mo and Y) showed decreased medium-accuracy; while for the others there was either no change (P) or there was increased medium-accuracy at the close.

In general all changes were small. Among the most marked variations, those sufficiently large to be significant, may be noted the following; greatest accuracy at the close in the case of Y (35 to 38 to 40), decreased medium-accuracy in the case of Mo (39 to 35 to 30), increased medium-accuracy in the case of Sh (44 to 44 to 52), increased inaccuracy (LA) in the case of Mo (19 to 27 to 32), and decreased inaccuracy for both Sh (18 to 17 to 07) and St (22 to 17 to 18).

From these data it is difficult to formulate any definite conclusions. That all subjects reacted to the various stimulating conditions in the same manner, with only minor variations throughout the investigation, seems definitely established. And in view of the slight changes which did occur it is evident that any influence which practice did exert was small.

Knowledge

It was felt that the large number of conditions employed and the fact that they were given in random order precluded the acquisition of knowledge. To determine whether knowledge of the experimental situation and procedure would effect any changes in the nature of the reactions, the following experiment was conducted with the same seven subjects whose records have been given individual treatment throughout. The apparatus was shown to them, and the procedure explained in detail. Then followed a period of record accumulation under this new condition, with full knowledge, during which attention was being called constantly to what was about to happen in the next exposure. Ten reactions to each of the original 144 conditions were thus secured. In Table XV these results are given, together with the observed proportions for the last 2880 reactions, and for the totals of each of the seven subjects.

TABLE XV

OBSERVED PROPORTIONS WITHOUT AND WITH KNOWLEDGE

Subjects	Without Knowledge						With Knowledge		
	At the Close			For the Totals			GA	MA	LA
	GA	MA	LA	GA	MA	LA			
G.....	39	46	15	38	45	17	42	43	15
Mi.....	33	40	27	30	41	29	34	38	28
Mo.....	38	30	32	38	35	27	37	33	30
P.....	39	30	31	39	29	32	37	33	30
Sh.....	41	52	07	41	44	15	49	44	07
St.....	36	46	18	34	48	18	38	45	17
Y.....	40	38	22	38	41	21	41	39	20

Eight conditions of movement. Nine combinations of intensities. Both right and left fixations.

An examination of this table shows a slight tendency toward greater perceptual accuracy with full knowledge; but, with a single exception (Sh), the differences are too small to be statistically significant. Thus the conditions of the investigation were such that the effectiveness of the controlled factor was sufficient to nullify the influence of such suggestibility as must have accompanied knowledge of what was happening to the extent that knowledge itself did not modify the nature of the perceived movement.

INDIVIDUAL DIFFERENCES

That individual differences were characteristic of the distributions of reactions, under all conditions, is established by even a casual examination of the fifteen tables of observed proportions given. In general, these differences did not greatly vary from the average for the group, nor from the general trend of the other subjects. There were exceptions, however, sufficiently great to be conspicuous as individual peculiarities.

G was highly susceptible to movement at the left, and was only slightly influenced by fixation.

Mi revealed a pronounced disposition toward perceived inequality of speed of movement of the two lights, with the result that all GA proportions with both lights moving, and MA proportions with one light moving, are extremely low.

Mo was highly sensitive to inequality of intensity, and was more susceptible to movement to the right than to movement to the left.

P's record is characterized by a rather high susceptibility to the influence of relative intensity.

Sh appears to have been practically immune to the influence of fixation, a peculiarity accentuating variations due to the influence of other factors.

St displayed the same susceptibility to movement of the light at the left as did G, and the same disposition toward perceived inequality of movement of the lights as Mi.

Summary

Inequality of intensity was found to be a positive factor definitely influencing the perception of movement. This influence functioned to increase the mobility of the dimmer light, and to decrease the mobility of the bright light. Whether this is a function of the relative size of the two lights, or of their relative light intensity, the data provide no basis for stating.

From the above the following phenomena may be expected, all of which are substantiated by the data.

Passing from lights of equal intensity to lights of unequal intensity, (1) increasing the intensity of the fixated light (*a*) decreases the perceived mobility of that light, and (*b*) increases the mobility of the light in indirect vision; (2) decreasing the intensity of the fixated light (*a*) increases the perceived mobility of that light, and (*b*) decreases the mobility of the light in indirect vision.

When one light only is moving and inequality of intensity is introduced, (1) increasing the intensity of the fixated light (*a*) decreases accuracy when the fixated light is moving, and (*b*) increases accuracy when the fixated light is stationary; (2) decreasing the intensity of the fixated light (*a*) increases accuracy when the fixated light is the moving one, and (*b*) decreases accuracy when the fixated light is the stationary one.

When both lights are moving at the same speed inequality of intensity is conducive to decreased accuracy.

Changes in absolute intensity were found to exert but a slight influence upon perceived movement. To the extent to which it does function, increased absolute intensity appears conducive to perceived equal mobility of the two lights.

The positional influence of the moving light appears to be a matter of individual susceptibility. Although the majority of our subjects displayed greater sensitiveness to movement at the right than to movement at the left, the tendency to favor movement at the left by those so inclined was so pronounced as to admit of no uncertainty.

Movement to the left was more accurately perceived than movement to the right. Whether this is due to anisotropic conditions of the retina or to kinæsthesia incident to habitual visual activity we are not prepared to say.

Direction of fixation, expressed in terms of fixation of the right *vs.* fixation of the left, gave inconclusive results. Expressed in terms of fixation *vs.* non-fixation the results are more definite. Perceived movement with fixation exceeds perceived movement in indirect vision.

Physical movement of the stimulating object is itself a positive factor in the perception of motion. This may be due to the streaming of the retinal image, or to the pursuit movement, or to both.

Practice was found to exert no pronounced influence upon the nature of the perceived motion; and knowledge only a slight influence at most.

THE RELATION BETWEEN EXTENT AND CONTRAST IN THE LIMINAL STIMULUS FOR VISION

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There are several ways in which the sensitivity of vision may be measured. Of these, the simplest of application is probably the use of the test-card of the ophthalmologist. In this case the size of the smallest letters which the subject is capable of reading is the basis of his rating as to visual acuity.

Another measure of visual sensitivity is of importance in photometry. Here the subject adjusts one part of a bright field, a few degrees in diameter, until it matches the remainder as nearly as possible, and the entire field becomes of nearly or quite uniform appearance.

In the first case, the letters of the test-card stand in wide contrast with the surface upon which they are printed. The ink has a reflection factor perhaps 1/15 or 1/20 of that of the card, and the measured quantity is the minimal size of letter which is just recognizable. In the case of the photometer, the areas of the two surfaces to be matched are gross, and the liminal difference in brightness becomes of importance. This has a value of the order of one per cent., instead of the 93 to 95 per cent. difference in brightness that exists between the card and the ink upon it.

It is not far to reason from this point that these two forms of visual sensitivity are special cases at the extremes of a continuous series of possibilities, and that through the entire range, from the smallest object visible under maximal contrast [1] to the smallest contrast visible with indefinitely

[1] The word *contrast* as used in this paper applies solely to the photometric values involved in the stimulus, entirely without reference to any qualitative modification due to retinal interaction. It has been found convenient to express this relation as the ratio of brightness-difference to brightness.

great extent in the visual field, there must be some sort of complementary relationship between the size of the object, on the one hand, and the brightness-difference which distinguishes it from its background, on the other, when the two are such that the object is just at the point of visibility. For each grade of contrast, there is a threshold size of object and *vice versa*. The quantitative relation between these two is the object sought in the present work.

The other two variables of the visual stimulus, namely, duration and brightness-level, are held constant in the present work. It is planned in subsequent work to investigate their effect more completely than has yet been done.

Visual acuity has been the subject of numerous investigations. The earliest statement of its value, attributed to Hooke (1), is to the effect that two stars separated by less than 30 seconds visual angle appear as one. Later (1754) Tobias Mayer (2) showed its dependence upon light-intensity, and in 1897 Koenig (3) reported what is at present the most complete set of data bearing upon this relation.

Aubert (4) showed that the separation of two white squares necessary in order that they might be seen as separate was greater under dull daylight than under bright; and he also showed that the threshold separation was greater when they were placed on a gray ground (of 40 per cent. of their own brightness) than when on black (1/57 of their own brightness). This would indicate that the dimension of the smallest visible object will increase when the contrast between it and its background is diminished. On the other hand, the contrast in this case is still large, as compared with the least difference in brightness visible as between large areas, such as the two elements of the photometer-field. In the latter, the two half-fields are about as 100 to 99 in intensity, while in the former the elements to be discriminated were as 100 to 40.

The dependence of visual sensitivity to brightness-difference upon the angular size of the object used was shown as early as 1867 by Aubert (5). Lasareff (6) published (1911) a series of results to the same general effect; namely, that the differential sensitivity increases (relative brightness-difference decreases) with increase in the visual angle under which a photometric field is observed.

What is true of these earlier investigations is true of the numerous attempts at the subject since then. They have either been investigations into visual acuity, with the grade of contrast modified to a relatively small extent from black and white; or they have been investigations as to the optimal field-size, especially for photometric practice; conditions in which the space dimensions are gross and the brightness-difference relatively not far from minimal. These extremes have, to the writer's knowledge, never been connected by the investigation of the intermediate region. The recent work of Luckiesh and Holladay (7) states no results for contrasts greater than about 3 per cent.

The Present Work

The plan of the present work was to arrange a series of test-objects of various sizes, from the smallest visible to the

largest practicable with the same apparatus; and to provide a device by which any of these could be shown in all grades of contrast, from the deepest black on white to the point of zero difference. The contrast was reduced from the maximum by having the subject view the object through an obliquely placed unsilvered plate-glass reflector, in which he saw the image of an extended bright surface. Thus the brightness of the "veil" so superimposed upon the test-object was added to that of the black object itself, as well as to its white background; and the brightness-ratio between the two was thus reduced. By separate control of the illuminations upon the test-object and upon the reflected surface, it was possible not only to vary the ratio between the effective brightness of the object and of its background, but also to keep the latter at a uniform brightness throughout the entire set of experiments, thus equalizing the adaptive factor, so that the results should truly represent the relation between the size of the object and its contrast with the background.

Apparatus and Methods. The arrangement of apparatus is shown in Fig. 1. The subject is seated with his head in a head-rest, and views the test-object at the center of a white screen *S*, at a distance of 6 meters, through an opening in the wall between two rooms. The plate-glass is shown at *V*, in which the subject sees the reflected image of a sheet of milk-flashed glass *O*, which is lit by a battery of lamps at *L*, enclosed in a light-tight compartment behind it. The screen *S* and the test-object are lit by lamps in boxes at L_1, L_1. The space from *L* to *B* is enclosed, light-tight except for the openings in the visual line shown in the figure, and serves the auxiliary purpose of a light-trap, cutting off or absorbing the light from *O*, which would otherwise find its way to the screen *S*. There were five sets of five lamps each, of various sizes, at *L*, which could be switched on separately. The boxes L_1, L_1 were each of four compartments vertically aligned, each compartment containing a lamp of a different size. The boxes could be slid in vertical guides to bring any pair of these to the level of the visual line. Thus by the use of different lamps and by reducing the voltage of the lamps used it was

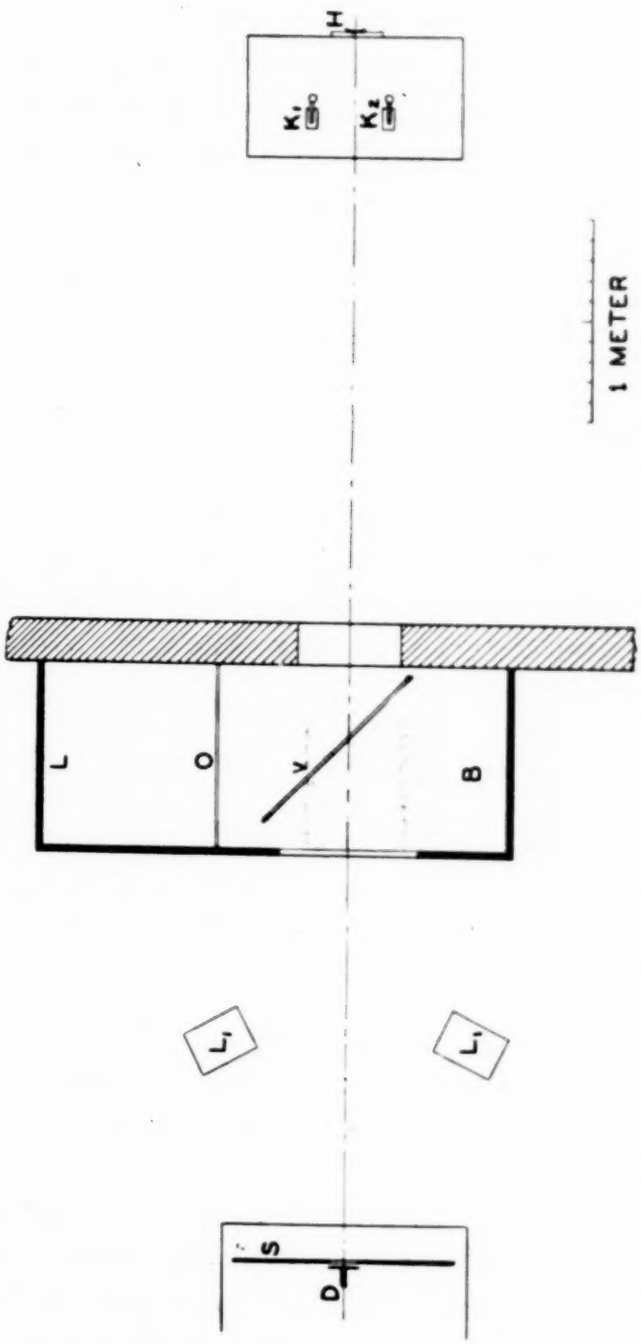

FIG. 1. General arrangement of apparatus. The subject sits with his head in the head-rest at *H*, and sees the test-object through the plate-glass at the center of the screen *S*. Superimposed on the screen he sees the image of the bright surface *O*, reflected in the plate-glass.

possible to bring the screen *S*, as viewed, and also the 'veil' (*O* seen reflected in the plate-glass *V*) independently to any brightness required. Thus it was possible while maintaining the brightness of the field close to constancy at 20 ml. to vary the contrast of the object from 100 per cent. (no veil at all) down to 1 per cent. by indefinitely small gradations. Daylight was excluded throughout all experiments, any systematic effect upon the pupil being excluded by the fact that the light intensity was constant.

The test-objects were made by pasting parallel strips of glossy photographic paper, exposed and developed to the deepest black, upon white card-board. The space between the strips was equal to their width, and this dimension is the unit, expressed in millimeters or minutes of visual angle, by which the particular object is designated. The length of the bars is three times their width, so that the entire figure might be described as a black square with a strip constituting its middle third cut out (Fig. 2). Since the light from L_1, L_1

FIG. 2. The form of the test-object. The space between the two bars is equal to their width and is the nominal dimension of the object. The length of the bars is three times this.

specularly reflected from the black surface did not enter the subject's eyes, the brightness of the black as seen from that point was very low, not more than 2.1 per cent. of that of the card upon which it appeared.

A set of such test-objects was prepared, of 0.797 to 16.02 minutes' size, the steps forming an approximate geometric series. The test-object was placed at the center of the screen *S*, upon a disc (Fig. 3) rotating at 120 revolutions per minute. The exposure consisted in the stoppage of the disc for the period of 0.17 second. This was effected by means of a magnetic clutch, shown in Fig. 3, bearing on its shaft a commutator which could be so set that the stoppage should

occur with the test-object in either the vertical or the horizontal position, at the will of the operator. When the subject (at *H*, Fig. 1) pressed the key K_1, the disc stopped as soon as

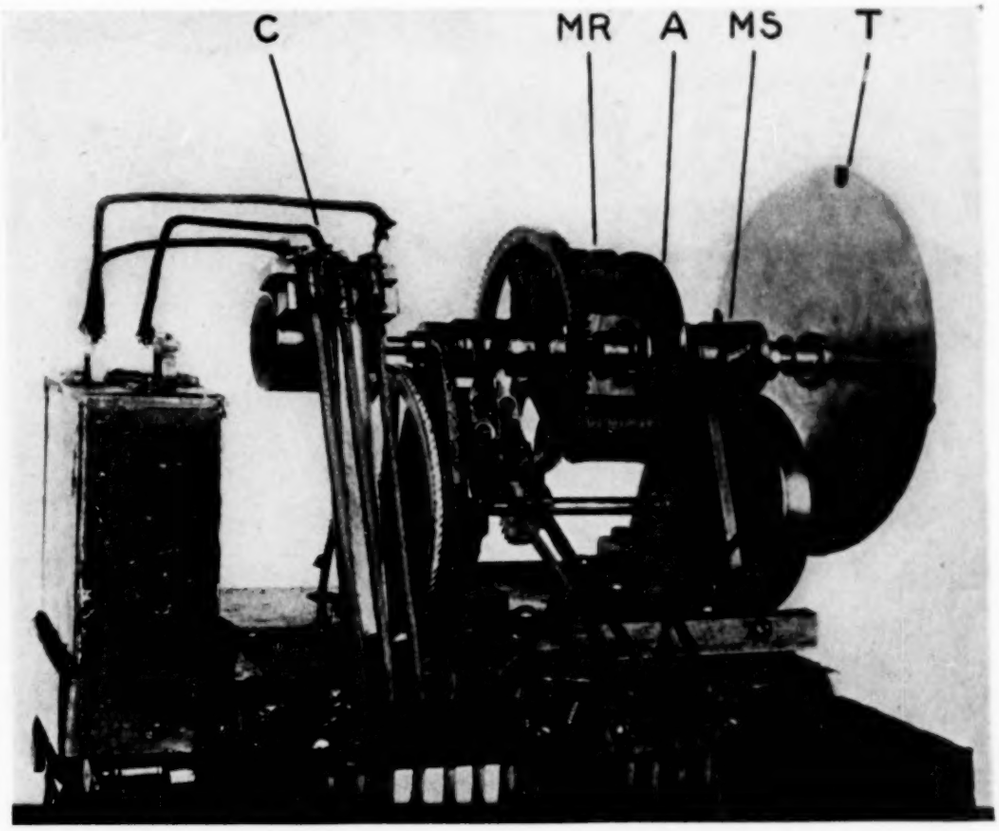

FIG. 3. The rotator at *D*, Figs. 1 and 4. The test-object is carried on the disc *T* which rotates with the armature plate *A*. *A* is pulled against either the rotating, magnet *MR* or the stationary one *MS*. When the commutator *C* (carried with the armature *A*) reaches a certain point, the circuit in *MR* is momentarily broken, *A* flies over to *MS* and the disc stops. It is restarted by the breaking of the circuit in *MS* at a switch on the pendulum-arc (Fig. 4).

it next reached the predetermined position. The restarting of the disc was timed by a switch on the arc of a pendulum, which was released simultaneously with the stopping of the disc by the breaking of the same electrical circuit.

The brightness of the field as it affects the subject's eye will be $s + v$, where s is the brightness of the screen *S* seen through the plate-glass *V*, and v is the brightness of the image of *O*, seen in the reflector *V*. Further, the brightness of the test-object bars will be $0.021s + v$, since these are 0.021 as

bright as the screen S when no veil is present. The 'contrast,' as the word will be used here, is the difference between these

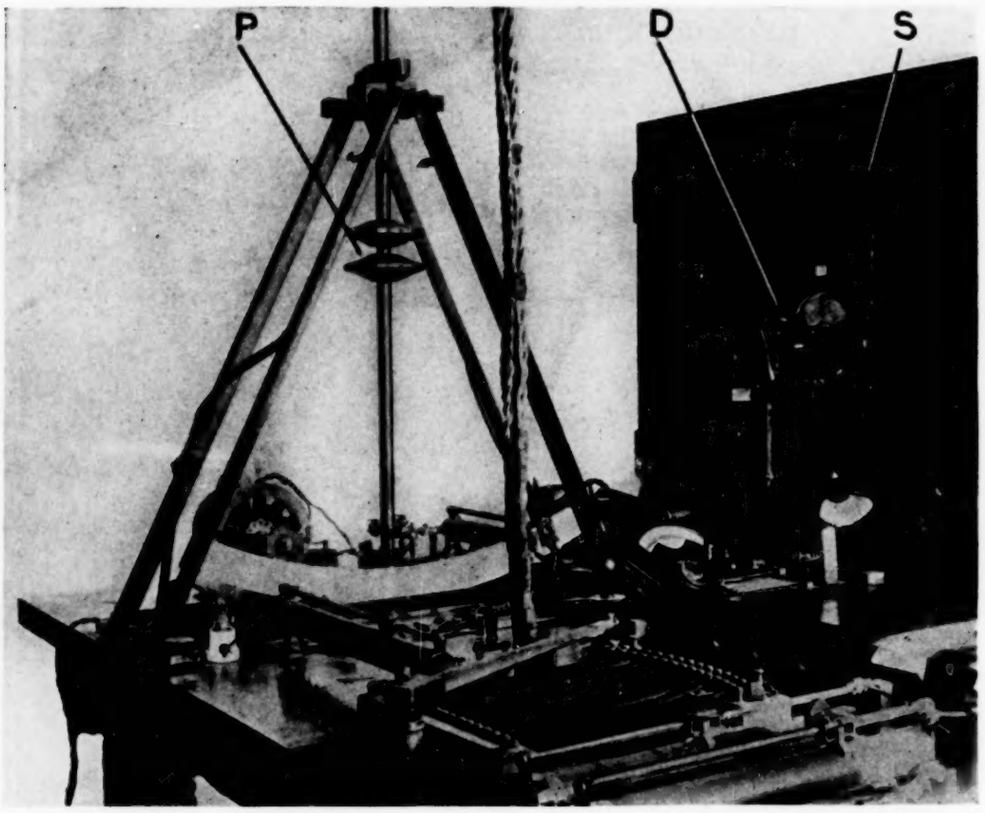

FIG. 4. General view of the timing apparatus. D is the rotating device (Fig. 3) at the center of the screen S (Fig. 1). The pendulum P restarts the rotation of the disc after an interval of 0.17 sec and so terminates the exposure.

two, divided by the background brightness, therefore equal to $\frac{.979s}{s+v}$.[2] This becomes equal to .979 when the veil is wholly dark. This value has arbitrarily and for convenience been placed at 100 per cent., being the maximal possible value of contrast obtainable with the present arrangement.

[2] It was found that there was a certain amount of stray light from the lamps used to light the veil which fell upon the screen S and thereby added to its effective brightness. By actual measurement this addition was found to be 0.00134 of the veil brightness v, which amount should be added to the numerator of this fraction to give the true value. By the photometric method used, this amount was already included in the value v in the denominator.

Corrections for this were made, and have been carried into Tables I and II. They are not of significant amount except in the last few lines of the tables, amounting to about 10 per cent. of the contrast-value in the last row.

With the help of the photometer, fifty steps in contrast were established, from 100 per cent. to 1 per cent., in an approximate geometric series, with the precaution that the field brightness, $s + v$, should always be close to 20 ml. For the separate threshold measurements, the method of serial groups was used. One of the test-objects was used first for a group of ten consecutive exposures with a grade of contrast that should yield not less than 90 per cent. right answers, then for a group of ten with the next lower contrast, and so on until the right answers were 60 per cent. or less. The score for each group (at a particular contrast) was the percentage right minus the percentage wrong answers, and the result from the single series of groups was the value of contrast, interpolated where necessary, corresponding to a 50 per cent. score. The exact method of interpolation has been described (**8**).

One series was run with each of the test-objects, in the order of their size, a value of contrast for each object being thus obtained. Such a test occupied two experimental sessions. The test-objects were then run in the reverse order, and so on until five serial results had been obtained with each of the test-objects.

The results given were so obtained from nine subjects, all men, chiefly of the Laboratory staff, and from other departments at Nela Park as available.

Results

The mean percentage threshold contrast for each subject and for each size of test object is given in Table I. In the last column are given the geometric means for all nine subjects. The relative probable errors of the corresponding averages are given in Table II. It was found by trial that the results from each subject, taken by themselves, fitted an equation of the form:

$$(C - a)(S - d)^m = b;$$

or

$$\log (C - a) + m \log (S - d) = \log b;$$

where C is the threshold contrast per cent., S the size of the

TABLE I

Minutes Visual Angle	Per Cent. Contrast									
	C	M	T	L	P	H	K	W	B	Mean
0.80		89.1	89.0	78.2			62.2		82.8	
0.99	47.0	39.1	50.2	43.8	56.0	57.0	35.3	74.0	44.3	48.5
1.17	26.6	21.1	34.0	27.7	33.2	38.7	22.1	51.4	26.2	30.1
1.35	17.7	15.2	23.9	19.8	23.3	30.5	15.1	32.7	17.3	20.9
1.63	12.6	9.62	16.0	12.4	14.0	23.6	10.7	22.9	11.6	14.1
1.93	9.25	7.13	11.6	8.75	10.4	17.4	7.76	13.4	7.66	9.96
2.41	6.42	4.62	8.37	6.46	7.86	12.3	5.12	9.02	4.76	6.87
3.20	3.93	3.29	6.85	4.02	6.10	9.26	3.96	6.19	3.44	4.92
3.95	3.29	2.54	4.97	3.23	4.33	6.46	3.20	3.92	2.81	3.71
5.67	2.55	1.95	3.50	2.35	3.17	4.20	2.34	2.94	2.13	2.71
7.98	2.07	1.60	2.91	1.90	2.71	2.98	1.81	2.23	1.75	2.16
11.31	1.72	1.38	2.22	1.58	2.30	2.24	1.54	1.84	1.65	1.80
16.02	1.50	1.27	1.85	1.42	1.79	1.96	1.34	1.61	1.51	1.57

Threshold contrast, per cent. brightness of background, for test-objects seen under various visual angles in minutes. The mean values in the last column are the geometric means of the nine values for the individual subjects.

corresponding object in minutes visual angle, and a, d, m and b are constants depending upon the subject and also upon the other conditions of the experiment.

If the data fit such an equation, it would follow that log $(C - a)$ and log $(S - d)$ should plot against each other in a straight line. By trial and error, the values of a and d were found for each subject, which should satisfy this condition with an accuracy corresponding to the value of the probable error. From the best-fitting straight line, the values of m and b were obtained, and the equation so derived for the mean values of C for the nine subjects in the form

$$C = a + b(S - d)^{-m}$$

is

$$C = 1.28 + 13.97(S - 0.56)^{-1.399}.$$

TABLE II

Minutes Visual Angle	Relative Probable Error of Contrast Values									
	C	M	T	L	P	H	K	W	B	Mean
0.80		.030	.042	.047			.016		.031	
0.99	.041	.092	.076	.047	.087	.044	.056	.036	.060	.021
1.17	.053	.048	.064	.016	.060	.022	.087	.032	.028	.017
1.35	.056	.051	.036	.050	.083	.047	.064	.025	.020	.017
1.63	.055	.030	.039	.053	.044	.049	.044	.032	.044	.015
1.93	.038	.047	.028	.047	.063	.043	.045	.015	.055	.015
2.41	.035	.061	.026	.072	.057	.055	.034	.038	.040	.016
3.20	.020	.044	.044	.038	.031	.036	.038	.035	.050	.013
3.95	.024	.063	.039	.035	.040	.034	.034	.018	.033	.012
5.67	.048	.056	.022	.042	.048	.043	.051	.011	.023	.014
7.98	.049	.055	.038	.026	.048	.016	.020	.028	.023	.012
11.31	.034	.052	.021	.038	.066	.036	.030	.013	.023	.013
16.02	.054	.056	.034	.032	.042	.030	.050	.031	.027	.014

Relative probable errors of the threshold values given in Table I. The probable error of the mean (E_M, last column) is computed by the formula $E_M = \frac{1}{N}\sqrt{\Sigma E^2}$, when $N = 9$ and the E's are the individual probable errors in the same line of the table.

Whether average values are significant when treated in this way is questionable. The constants of this equation are not the means of the corresponding constants for the individuals; but the fact remains that the equations for the several subjects fitted the respective data with surprising closeness, considering the magnitudes of the probable errors.[3] The mean results (last column, Table I) are shown to logarithmic coördinates by the circles in curve *C*, Fig. 5. The dotted

[3] The actual fitting described here was done with the uncorrected results. From the mean results it was found, however, that the fit was equally good for the corrected and for the uncorrected results, the difference in the respective equations consisting chiefly in the change in the constant a by the maximal amount of the correction for C, and in very slight secondary changes in b and m.

extensions of the curve have been plotted to values computed from the equation, and Fig. 6 is the logarithmic straight-line

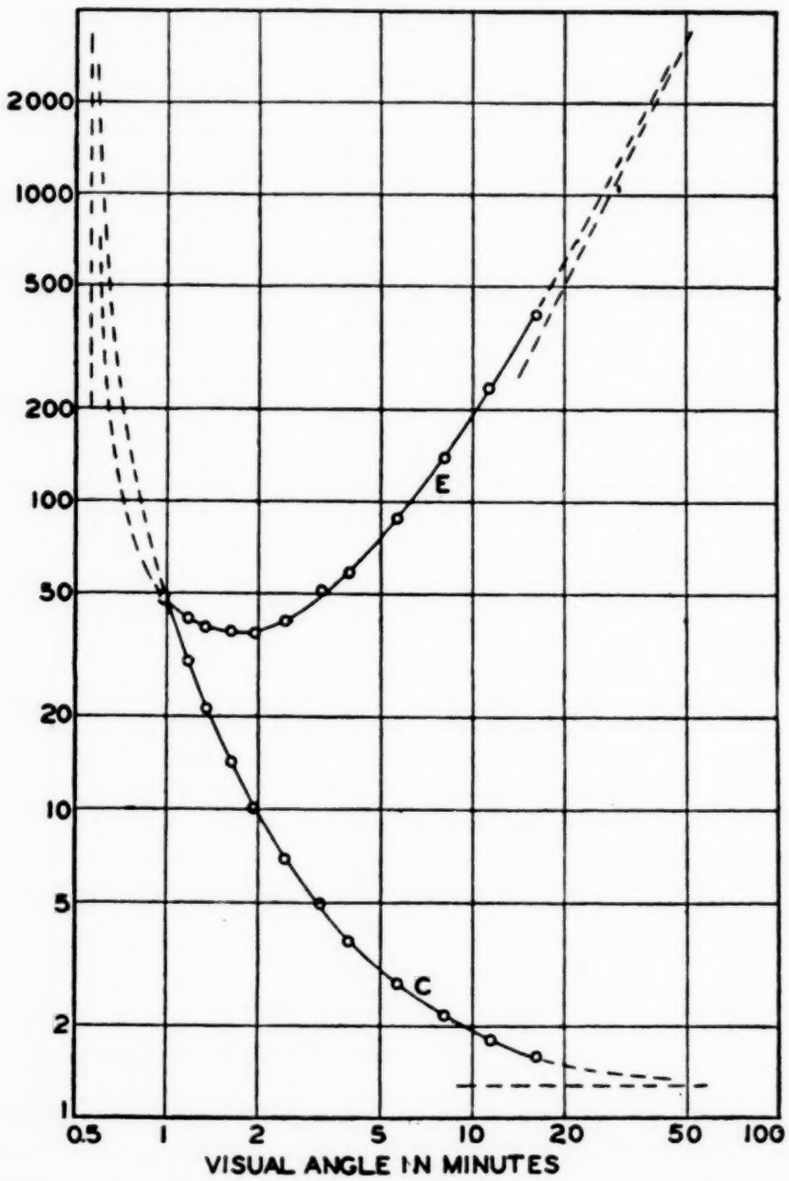

FIG. 5. Curve *C*. Geometric mean threshold, per cent. contrast, for nine subjects, and for various sizes of test-object. *E*. Relative energy of the threshold object. Both plotted logarithmically. Brightness 20 ml., exposure-time 0.17 sec.

plot, incidental to the determination of the constants of the equation, showing the closeness of fit of the data. Fig. 7 is curve *C* of Fig. 5 plotted in simple (non-logarithmic) co-ordinates.

Discussion

The form of the equation to which the results are fitted involves two 'threshold' constants. These are a and d. Obviously, when $S = d$, C must become infinite; similarly

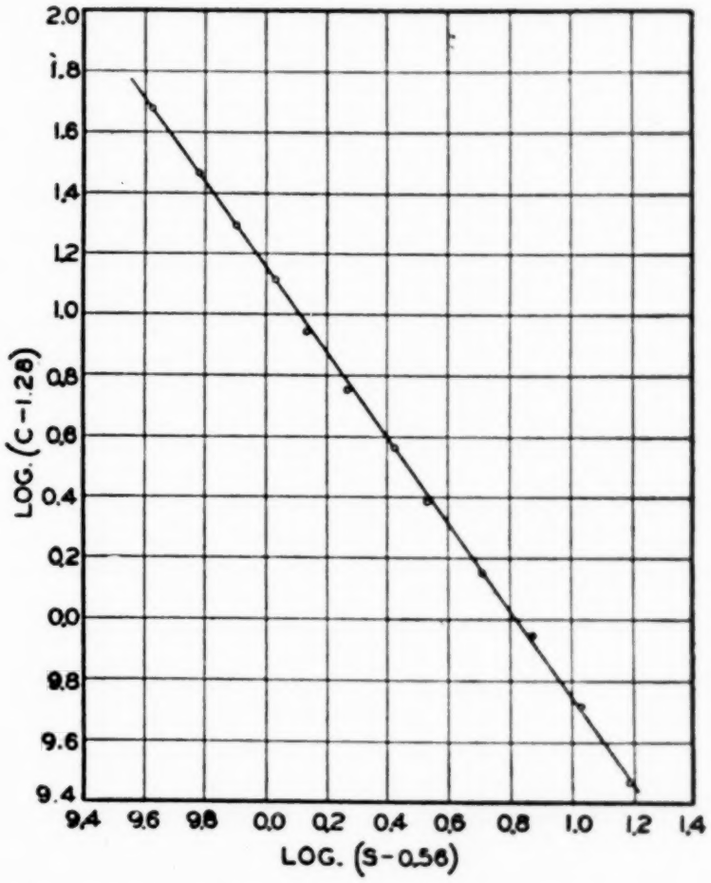

Fig. 6. The plot from which the equation of curve *C*, Fig. 5, was derived.

when $C = a$, S becomes infinite. The two assumptions involved correspond to what is generally accepted: that visual acuity has an absolute finite limit, which is the threshold when other conditions, including contrast, are at their best; and that the least perceptible brightness-difference likewise has an absolute lower limit when the spatial magnitude of the discriminated elements and other conditions are the most favorable. It was first assumed that the relation between $C - a$ and $S - d$ was an equilateral hyperbola, of the form: xy = a constant, but it soon appeared that this was not the case. The data did, however, fit such an equation very well

when the exponent of $(S - d)$ was increased to a certain value greater than that of $(C - a)$.

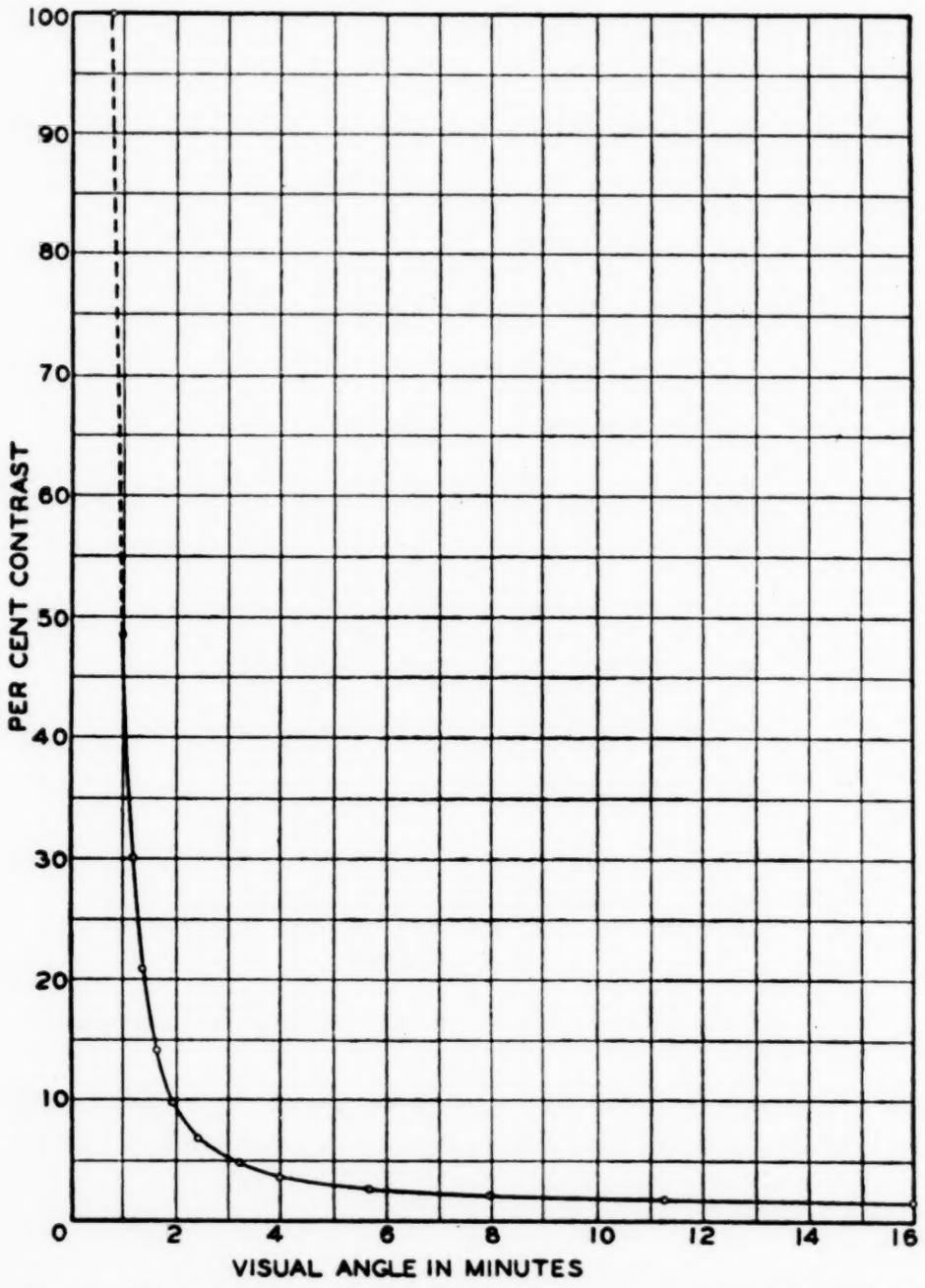

FIG. 7. Size of test-object against threshold per cent. contrast in simple (non-logarithmic) coördinates. Brightness 20 ml., exposure time 0.17 sec, same data as curve *C*, Fig. 5.

While there appears to be rational ground for using the constants *a* and *d* as subtractors, the rest of the equation is entirely empirical. Obviously, the refractive condition of the

eye is a factor of importance for a very small object, as it cannot possibly be for an object twenty times as large. The identical amount of blurring from the inaccuracy of the retinal image will be a potent factor in the one case, and an insignificant factor in the other. On the other hand, with test-objects of large extent, and seen in very low contrast, the interaction of the retinal receptors comes to play an important part.

Thus it might appear that the relationship is dual; that, for small sizes of test-object, the limit of vision depends largely upon an actual physical intermixture of the pencils of light corresponding to the images of the separate elements of the test-object; while for the larger objects and the lower contrasts, the extent of this intermixture is insignificant, the limit of vision depending in the main upon the behavior of the end-organs in the retina, and of their neural connections. It is interesting to note the course of the minimal energy requirement of the stimulus, as the size of the object increases (curve *E*, Fig. 5). The energy is negative in this case, and 100 units represent the amount cut out when a square of the black, having a brightness equal to 0.021 of that of the screen and subtending one minute of angle at the eye of the subject, replaces an equal area of the white screen at 20 ml. brightness. The conspicuous fact is that the energy is a minimum, for the average, when the unit dimension of the test-object subtends slightly less than 2′ of angle at the eye.

Summary

In the foregoing work, the aim was to determine the degree of contrast required for the threshold of form visibility of a series of test-objects. The limits of the series were set (1) by the fact that an object of 16′ visual angle was the largest practicable with the apparatus used for the smallest one and (2) by the fact that the maximal contrast obtainable by the method used was black on white, the former having a reflection coefficient equal to 0.021 of that of the latter. The smallest object possible with any subject was the one that could be seen with not more than this grade of contrast. The bright-

ness of the field was kept uniformly at 20 ml., and the exposure-time was 0.17 sec.

The relationship between size of object S (minutes visual angle) and contrast C (per cent. of maximum) was found to agree closely with an equation of the form:

$$(C - a)(S - d)^m = b,$$

in which a and d are the values that C and S will approach asymptotically, and m and b are constants.

For each of nine subjects the average values of C and S agree well with an equation of this form, but the constants of the equations show individual differences. Again, the geometric mean values of C for all subjects can also be well fitted to a similar equation.

While the results fit the above equation fairly well, the assumption that the relationship is identical at the two extremes is not wholly justified, either *a priori* or as a conclusion from the experimental data.

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